

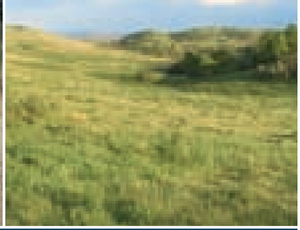


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Challenges and opportunities for carbon sequestration in grassland systems

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
Food and Agriculture Organization of the United Nations (FAO)

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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.

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.

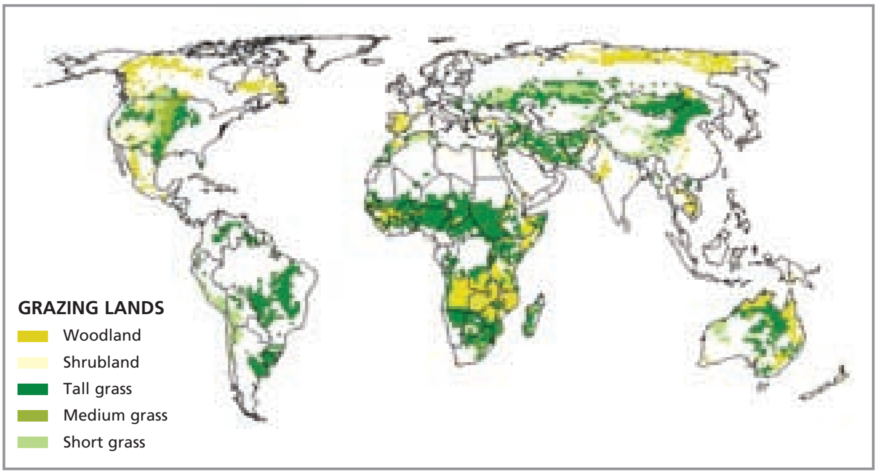
The opportunities to benefit from grassland practices that sequester carbon can be greater too. The large populations of people who depend directly on grasslands tend to be poor and vulnerable to climate variability and climate change. Implementing practices to build – or rebuild – soil carbon stocks 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

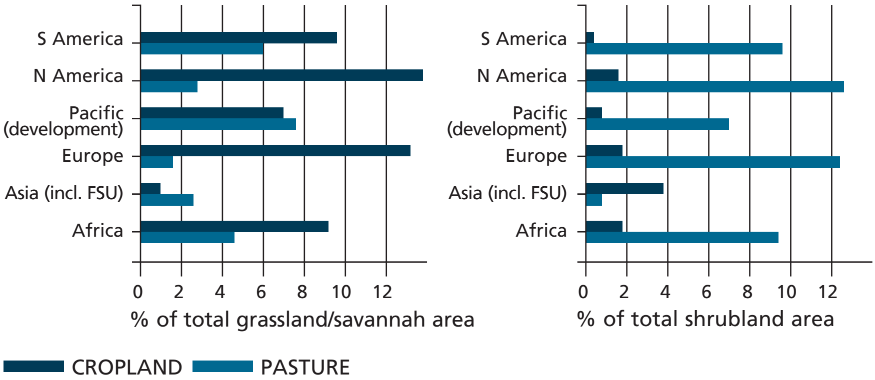


FIGURE 1: **Percentage of native grassland/savannah and shrubland that has been converted to cropland and pasture**

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

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).

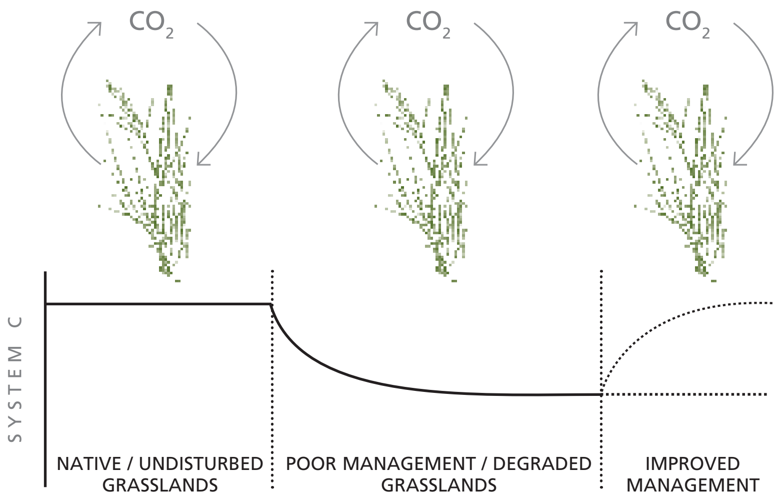


FIGURE 2: **Conceptual diagram illustrating how past land management has led to depletion of grassland soil carbon stocks due to practices that decrease carbon uptake. Implementation of improved management practices can lead to enhanced carbon uptake, restoring ecosystem carbon stocks and sequestering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

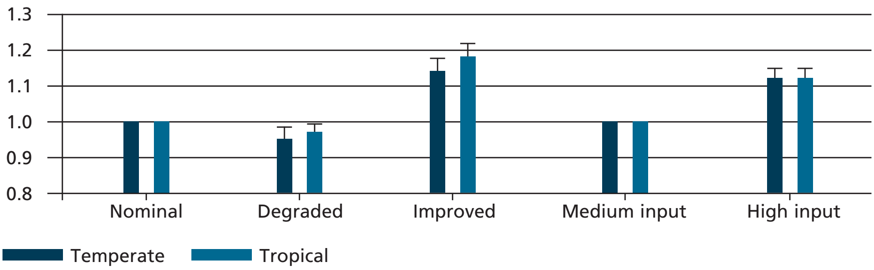
[1] Tg = 10^{12}g

BOX 2: **Full GHG accounting**

When mineral soil N content is increased by N additions (i.e. fertilizer), a portion of that N can be transformed into N_2O as a by-product of two microbiological processes (nitrification and denitrification), and lost to the atmosphere. Coincidental introduction of large amounts of easily decomposable organic matter and NO_3^- from either a plough down of cover crop or manure addition greatly stimulates denitrification under wet conditions (Mosier, Syers and Freney, 2004). Some practices intended to sequester atmospheric carbon in soil could prompt increases in N_2O fluxes.

For example, fertilization increases soil mineral N concentrations, leading to increased N_2O fluxes, particularly in wetter environments. N_2O is the most potent biogenic GHG in terms of global warming potential, with a radioactive forcing 296 times that of CO_2 (IPCC, 2001). Management activities that add mineral or organic N – fertilization, plant N_2 fixation, manure additions, etc. – augment naturally occurring N_2O emissions from nitrification and denitrification by 0.0125 kg N_2O kg N applied^{-1} (Mosier *et al.,* 1998). Agriculture contributes significantly to total global N_2O fluxes through soil emissions (35 percent of total global emissions), animal waste handling (12 percent), nitrate leaching (7 percent), synthetic fertilizer application (5 percent), grazing animals (4 percent) and crop residue management (2 percent). Agriculture is the largest source of N_2O in the United States of America (78 percent of total N_2O emissions), Canada (59 percent) and Mexico (76 percent).

CH_4 emissions from ruminant animals comprise about one-third of non-CO_2 GHG emissions from agriculture (IPCC, 2007a). To the extent that practices that sequester carbon lead to increased stocking rates, CH_4 fluxes would increase, potentially offsetting mitigation due to sequestration (Soussana *et al.,* 2007). CH_4 emissions from ruminant animals are a measure of production inefficiency – more CH_4 emitted means less of the carbon consumed by livestock is converted to product (FAO, 2006; Leng, 1993). The complement is also largely true: increasing production efficiency reduces CH_4 emission. Consequently, investments to reduce CH_4 emissions will lead to increased production efficiency.



These factors estimate proportional carbon sequestration or loss (i.e. through degradation) given departure from nominal management practices. Medium inputs require one external input (e.g. fertilizer improved species, etc.) whereas high inputs require more than one external input. These management factors are presented as proportional increases in carbon stocks rather than carbon sequestration rates, so that the factors can be applied to all soils.

FIGURE 3: **Grassland management factors for temperate and tropical regions**

Source: Figure reproduced from Ogle, Conant and Paustian, 2004

would reduce the time that manure decomposes in anaerobic piles and lagoons, reducing emissions of CH_4 and N_2O. IPCC (2007a) estimates the technical potential for reduction of CH_4 emissions from manure to be 12.3 Tg C yr^{-1} by 2030; N_2O emissions could also be reduced. Adding manure in one place to build soil carbon stocks is offset by removal, or what would be carbon inputs in another place (by forage or feed harvest). The balance between these has not been well characterized. Summary data synthesized by climate region are presented in Figure 3.

Globally, an estimated 0.2—0.8 Gt[2] CO_2 yr^{-1} could be sequestered in grassland soils by 2030, given prices for CO_2 of USD20–50/tonne (IPCC, 2007a). Although both fertilization and fire management could contribute to carbon sequestration, most of the potential sequestration in non-degraded grasslands is due to changes in grazing management practices. Estimated rates of carbon sequestration per unit are lower than those for sequestration on agricultural land, but sequestration potential is comparable to that of croplands because grasslands cover such a large portion of the earth's surface (Figure 4). Nearly 270 million ha of grassland worldwide have been degraded to some degree

[2] Gt = 10^{15}g

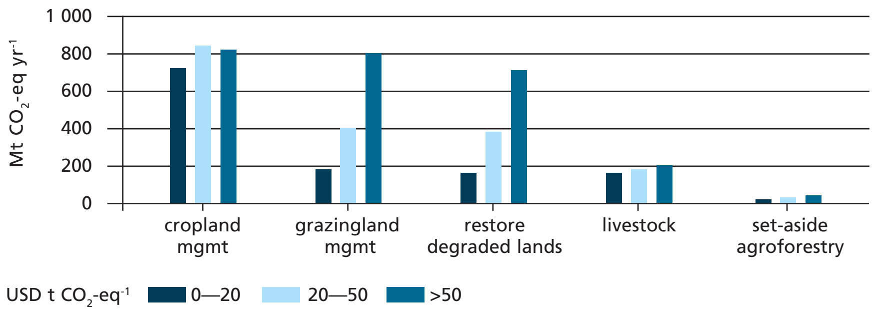


FIGURE 4: **Estimates of carbon sequestration potential for several mitigation measures at varying carbon prices**

Source: IPCC, 2007a

by mismanagement (Oldeman, 1994; Bridges and Oldeman, 1999). Much of this land can be rehabilitated by enhancing plant productivity, capturing water resources and using them more efficiently, or improving soil fertility; doing so could sequester about as much carbon as could be sequestered in grasslands (0.15—0.7 Gt CO_2 yr^{-1} depending on carbon prices) (IPCC, 2007a).

REDUCED CARBON EMISSIONS THROUGH REDUCED GRASSLAND DEGRADATION

Grasslands contain a substantial amount of the world's soil organic carbon. Integrating data on grassland areas (FAOSTAT, 2009) and grassland soil carbon stocks (Sombroek, Nachtergaele and Hebel, 1993) results in a global estimate of about 343 billion tonnes of C – nearly 50 percent more than is stored in forests worldwide (FAO, 2007).

Just as in the case of forest biomass carbon stocks, grassland soil carbon stocks are susceptible to loss upon conversion to other land uses (Paustian, Collins and Paul, 1997) or following activities that lead to grassland degradation (e.g. overgrazing). Current rates of carbon loss from grassland systems are not well quantified. Over the last decade, the grassland area has been diminishing while arable land area has been growing, suggesting continued conversion of grassland to croplands (FAOSTAT, 2009). When grasslands are converted to agricultural land, soil carbon stocks tend to decline by an average of about 60 percent (Paustian, Collins and Paul, 1997; Guo and Gifford, 2002).

Grassland degradation has also expanded (Bai *et al.*, 2008), probably contributing to the loss of grassland ecosystem carbon stocks. Arresting grassland conversion and degradation would preserve grassland soil carbon stocks. The magnitude of the impact on atmospheric CO_2 is much smaller than that due to deforestation, but preserving grassland soil carbon stocks serves to maintain the productive capacity of these ecosystems that make a substantial contribution to livelihoods.

PRACTICES THAT SEQUESTER CARBON IN GRASSLANDS OFTEN ENHANCE PRODUCTIVITY

An important argument in favour of grassland carbon sequestration is that implementation of practices to sequester carbon often lead to increased production and greater economic returns. Forage removal practices that disturb the system and prompt carbon losses usually reflect attempts to enhance forage utilization, but the complement is not necessarily true: practices that sequester carbon do not necessarily result in reduced forage utilization.

Reducing the amount of carbon inputs removed, or increasing production, carbon inputs or below-ground allocation, could all lead to increasing soil carbon stocks (Conant, Paustian and Elliott, 2001). Grazing management can lead to decreased carbon removal if grazing intensities are reduced or if grazing is deferred while forage species are most actively growing (Kemp and Michalk, 2007). Sustainable grazing management can thus increase carbon inputs and carbon stocks without necessarily reducing forage production. Grazing management can also be used to restore productive forage species, further augmenting carbon inputs and soil carbon stocks.

Other practices that enhance production, such as sowing more productive species or supplying adequate moisture and nutrients, also result in greater carbon uptake, ecosystem carbon stocks and forage production (Conant, Paustian and Elliott, 2001) (Box 3).

BOX 3: Which grassland management practices increase carbon stocks?

1. **Grazing management** can be improved to reverse grazing practices that continually remove a very large proportion of aboveground biomass. Implementing a grazing management system that maximizes production, rather than offtake, can increase carbon inputs and sequester carbon.

2. **Sowing improved species** can lead to increased production through species that are better adapted to local climate, more resilient to grazing, more resistant to drought and able to enhance soil fertility (i.e. N-fixing crops). Enhancing production leads to greater carbon inputs and carbon sequestration.

3. **Direct inputs of water, fertilizer or organic matter** can enhance water and N balances, increasing plant productivity and carbon inputs, potentially sequestering carbon. Inputs of water, N and organic matter all tend to require energy and can each enhance fluxes of N_2O, which are likely to offset carbon sequestration gains.

4. **Restoring degraded lands** enhances production in areas with low productivity, increasing carbon inputs and sequestering carbon.

5. **Including grass in the rotation cycle** on arable lands can increase production return organic matter (when grazed as a forage crop), and reduce disturbance to the soil through tillage. Thus, integrating grasses into crop rotations can enhance carbon inputs and reduce decomposition losses of carbon, each of which leads to carbon sequestration.

Improved management techniques can increase forage production and reduce feed costs, financially benefiting producers. As forage production increases, an ancillary benefit may lie in increased sequestration of atmospheric carbon. Indeed, Gifford *et al.* (1992) noted that improved pasture management is an important consideration when computing a

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national carbon budget. A variety of grassland management practices lead to near-term increases in both production and sequestration of carbon, and practices that sequester carbon often enhance producer income. Practices that reduce offtake – through grazing or harvest – tend to enhance carbon inputs, building carbon stocks. Thus, grazing management practices that increase carbon inputs by increasing production can sequester carbon. Also, practices that increase production inputs by enhancing soil fertility or sowing more productive species can help to build up soil carbon stocks. Directly introducing more carbon to the system through organic matter (e.g. manure) additions will also lead to increased carbon stocks, although it has been pointed out that increases are gained at the expense of carbon inputs where feed crops are grown (Conant, Paustian and Elliott, 2001).

In addition to enhancing forage production and food security, many land management practices that sequester carbon prompt other changes in environmental processes that are beneficial for other reasons. Practices that sequester carbon in grassland soils tend to maximize vegetative cover, reducing wind and water-induced erosion (Follett, Kimble and Lal, 2001). Reducing sediment load increases water quality while reducing airborne particulate matter improves air quality. Carbon sequestering practices can also enhance ecosystem water balance; building soil organic matter stocks tends to enhance water infiltration and soil moisture status in arid-semi-arid environments (Unger *et al.*, 1991). In many cases practices that sequester carbon can lead to greater biodiversity (Bekessy and Wintle, 2008).

	CO_2	CH_4	N_2O	AGREEMENT	EVIDENCE
Grazing intensity	+/-	+/-	+/-	*	*
Increased productivity (e.g. through fertilization)	+		+/-	**	*
Nutrient management	+		+/-	**	**
Fire management	+	+	+/-	**	*
Species introductions (incl. legumes)	+		+/-	*	**

TABLE 1: **Mitigative effects of various aspects of grazing land improvement**

Source: Reproduced from IPCC, 2007a

Most grassland management practices with the potential to sequester carbon were developed to address issues other than carbon sequestration. For example, expanding grasslands through agricultural set-asides and rehabilitating degraded rangelands are often intended to arrest wind and water erosion (Lal, 2009a). Practices that preserve the habitat, like grassland preservation, rehabilitation, etc., can preserve species and biodiversity. A variety of practices that integrate grass species into arable crop rotation (for example, catch crops used to retain nutrients, cover crops to reduce erosion, grass crops in rotation) sequester carbon and also retain nutrients in agricultural systems, reducing downstream pollution (Stevens and Quinton, 2009).

PRACTICES THAT SEQUESTER CARBON IN GRASSLANDS CAN ENHANCE ADAPTATION TO CLIMATE CHANGE

Mitigation investments are crucially important for reducing the impacts of climate change, but GHG concentrations will continue to increase for decades despite implementation of even the most aggressive climate policies (IPCC, 2007a). Therefore, adaptation is an important response to climate change that should begin now (IPCC, 2007b). Because yield reductions under drought, heat stress, floods and other extreme events will be the most consequential, negative impacts of climate change, efforts to adapt to a changing climate should focus on increasing the resilience of management systems (FAO, 2008a; WMO, 2007). The increasing frequency of droughts in the drylands (Thornton *et al.*, 2008) and droughts of longer duration are expected to have a substantial negative effect on the sustainability and viability of livestock production systems in semi-arid regions. Grassland management practices maximize the infiltration, capture and utilization of precipitation for production (Woodfine, 2009). In cases where sustainable grazing management increases soil carbon stocks, soil water holding capacity increases. Both facets of enhancing water balance will increase drought resilience.

Grassland management practices that sequester carbon tend to make systems more resilient to climate variation and climate change: increased soil organic matter (and carbon stocks) increases yields (Vallis *et al.*, 1996; Pan *et al.*, 2006); soil organic matter also enhances soil fertility, reducing reliance on external N inputs (Lal, 2009b). Surface cover, mulch and soil organic matter all contribute to a decrease in interannual variation in yields (Lal *et al.*, 2007); and practices that diversify cropping systems, such as grass and forage crops in rotation, sequester carbon and enhance yield consistency.

Agricultural practices intended to mitigate GHG emissions could increase vulnerability to climate variation and climate change, if they increase the energy supply from food production systems (e.g. to supply biomass energy), or prevent arable land from being cultivated (e.g. afforestation). Similarly, actions intended to foster adaptation could lead to increased emissions: e.g. increased N fertilization (and N_2O release) to enhance yields or harvest of stover for conversion to biofuels (IPCC, 2007a). However, practices that minimize soil disturbance and maintain good ground cover, restore soil carbon stocks and related soil biological activity, diversify crops and integrate crop/livestock production, will tend to increase soil carbon stocks and enhance resilience to drought and climate change (Woodfine, 2009).

POTENTIAL INCOME FOR PRACTICES THAT SEQUESTER CARBON

One of the main arguments for grassland sequestration is that the impending climate impacts are real and potentially severe, so all options to reduce GHG emissions should be pursued. The principle of comparative advantage suggests that a wider range of options should generate lower costs initially and overall. The potential contribution of grassland, forestry and agricultural sequestration to mitigate GHG emissions is large – together rivalling the potential emission reductions from the energy supply, transportation, buildings, waste and industrial sectors at low prices for carbon (USD20/Mg CO_2) and exceeding all sectors at high carbon prices (USD100/Mg CO_2) (IPCC, 2007b). The Intergovernmental Panel on Climate Change (IPCC) (2007b) estimated that grasslands, forestry and agriculture would sequester approximately 8 Gt CO_2 yr^{-1} given carbon prices of USD100/Mg CO_2; including reduced emissions from deforestation and degradation would maintain an additional 4 Gt CO_2 yr^{-1} in the soil, raising total contribution of the land sectors to about one-third of total annual global emissions (i.e. 12 Gt CO_2 yr^{-1} out of 30 Gt CO_2 yr^{-1}; Figure 5). Substantial amounts of CO_2 emission from the land sector and large potential for sequestration with changes in land management are among the most important arguments in favour of terrestrial sequestration.

Some practices that sequester carbon require land managers to forego optimal harvest (e.g. reducing forage offtake), tolerate reduced yields (e.g. reduced stocking rates) or change land use (e.g. cessation of grazing of vulnerable soils). Others require investments in new equipment that could be substantial (e.g. for seeding, irrigation or fertilization). However, the primary investments necessary for successful widespread adoption of many of the land management practices that enhance ecosystem carbon

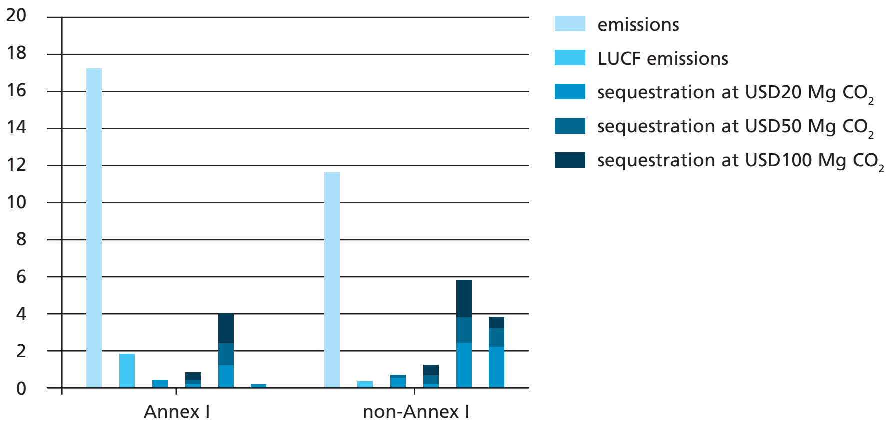

FIGURE 5: Emissions, emissions from land-use change/forestry (LUCF) and sequestration potential at USD20, 50 and 100 per Mg CO_2 for agricultural, grassland, forest and REDD activities

Source: IPCC, 2007b

storage are knowledge, education and information. Most of the materials required for the implementation of many practices that sequester carbon (e.g. improved species, legumes, grazing management, fire management, etc.) are often no different than those required for degradative land management practices – they differ primarily in their implementation. Technical requirements are often modest and marginal abatement costs are estimated to be negative in some cases (such as adoption of no-tillage in the United States of America and the United Kingdom) (Kelly, Redmond and King, 2009; Creyts *et al.*, 2007).

Carbon emissions from land-use change arise primarily from countries that are exempt from emission reductions under the Kyoto Protocol. Widespread disturbance and degradation (Oldeman, 1994) and continuing deforestation make carbon sequestration and preservation (i.e. United Nations Collaborative Programme on Reducing Emissions from Deforestation and Forest Degradation [UN-REDD]) substantial sequestration opportunities in these developing countries (Conant and Paustian, 2002a; Benitez *et al.*, 2007; Lal, 2000). Engagement of developing countries in emission reduction activities that simultaneously enhance adaptive strategies is another argument in favour of grassland carbon sequestration (Jung, 2005). Given modest costs and the use of existing technologies, grassland carbon sequestration in developing countries could be enacted in the near term, offsetting emissions from other sectors now, allowing time for the larger investments required to reduce directly emissions from burning fossil fuels (Ellis *et al.*, 2007). Investments in carbon sequestering practices in developing countries that increase grassland/livestock efficiency or productivity and reduce vulnerability to impacts of climate change (i.e. enhancing adaptation) are likely to promote relatively immediate sustainable returns. The economic, environmental and social costs of land degradation are substantial (FAO, 2008b) and investments in sustainable grassland management tend to be an efficient use of limited development resources (The World Bank, 2007). New knowledge about best practices is likely to be required in order to have a meaningful impact in much of the developing world.

CHAPTER 4
Challenges

DEVELOPING WORKABLE POLICIES AND INCENTIVES IS DIFFICULT

The principle of "common but differentiated responsibilities" in the Kyoto Protocol regulates emissions for Annex I countries, but encourages developing country participation through the CDM. The current rules for the land-use, land-use change and forestry projects under the CDM, adopted at the Seventh Conference of the Parties (COP7) in 2001, resulted in an agreement that permits afforestation and reforestation carbon offset projects in developing countries, but with complex monitoring and reporting requirements, and the exclusion of emissions from deforestation or credits for agricultural or grassland sequestration (Schlamadinger *et al.*, 2007). Emissions from afforestation, reforestation and deforestation since 1990 are reported as part of United Nations Framework Convention on Climate Change (UNFCCC) official National Communications that will determine compliance with the Kyoto Protocol emission reduction targets. The CDM is designed to lower costs for achieving that goal while encouraging participation of non-Annex I countries and helping to foster sustainable development (Paulsson, 2009). Many developing countries strongly supported the inclusion of sinks in anticipation that emission caps would substantially increase the flow of aid – in the form of emission offset projects – from developed countries (Boyd, Corbera and Estrada, 2008). The inclusion of sinks through the CDM allows participation of a wide range of actors in emission reduction efforts, but places strict limits on only a subset of those participants. Balancing emission reductions for large emitters with mechanisms that engage small emitters remains a key component of international negotiations.

DEMONSTRATING ADDITIONALITY IS A FORMIDABLE CHALLENGE[1]

Under the Marrakesh Accords, projects that reduce GHG emissions "below those that would have occurred in the absence of the registered CDM project activity" are eligible for credit under the CDM (UNFCCC, 2001). Key challenges for projects from uncapped countries – for all types of offset projects, not just sequestration projects (Reilly and Asadoorian, 2007) – is proving to be counter-factual: convincingly demonstrating what would have been done in the absence of carbon sequestration incentives. Methods of assessment have been developed (Chomitz, 2002) and various rules have been proposed (Wiley and Chameides, 2007) and applied (see Paulsson, 2009; Palm, Ostwald and Reilly, 2008) to address additionality and leakage. To date, the results of carbon emission offsets under the Kyoto Protocol have been mixed (Paulsson, 2009). Several projects of dubious emission reduction value have been approved (Wara, 2007), and a few sequestration projects have been accepted. Research relating to the feasibility of the CDM continues to address this issue (Paulsson, 2009).

Demonstrating additionality requires information other than sampling of biomass or soil carbon stocks (Lovbrand, 2004). Policies that incentivize adoption of behavioural (i.e. land management) changes are confronted by additionality and the potential for perverse incentives, which in the case of forestry and agricultural sequestration could encourage landowners to get rid of ecosystem carbon through tillage, fire or harvest so that they could then be paid to re-sequester it. All policies, grants or investments that fund or incentivize some action implicitly assume that the action would not have taken place in the absence of policy implementation. The difficulty is compounded in terrestrial carbon sequestration projects because the direct, human-induced changes in carbon stocks must be distinguished from changes in carbon stocks driven by natural processes (e.g. biomass carbon stock recovery after a fire), and indirectly by human actions (e.g. enhanced biomass carbon stocks driven by CO_2 fertilization or N deposition; increased soil carbon stocks driven by shifts

[1] Greiner and Michaelowa, 2003; Schneider, 2009; Grainger, 2009

in species composition) (Lovbrand, 2004). In theory, such changes could be documented by sampling, but disentangling drivers of carbon stock changes remains challenging (Alexandrov and Yamagata, 2004; Canadell *et al.*, 2007; Smith, 2005).

The anticipated low costs of grassland carbon sequestration are intimately intertwined with the additionality issue – if barriers (costs) are low for adopting practices that sequester carbon, they are more likely to be adopted in the absence of policies to promote them. Documenting changes in biomass or soil carbon stocks will require some kind of measurement coupled with extrapolation or interpolation (Conant *et al.*, 2009). These measurements differ from those required for other types of offset projects; they contribute more significantly to project costs, and economies of scale may not be as effective at reducing costs. Enacting a project in which several landowners carry out carbon sequestering practices would require documenting the effect of those practices (collectively or individually) on each parcel. The difficulty lies not in measuring carbon stocks but in devising measurement/ monitoring/verification systems that are accurate yet cost-effective (Conant *et al.*, 2009).

CARBON SEQUESTERED IN GRASSLAND SYSTEMS IS SUBJECT TO REVERSALS

Disturbance can cause rapid reversals of previously sequestered carbon (Galik and Jackson, 2009). Such disturbances can be large or small, intentional or unintentional (Page *et al.*, 2002). The CDM has dealt with this issue by developing temporary Certified Emission Reductions (CERs) for five- or twenty-year periods (Dessai *et al.*, 2005), while other standards reduce emission reduction credits to buffer against losses[2]. Impermanence decreases the value of sequestration projects compared with emission reduction projects, and increases uncertainty and transaction costs (van Kooten, 2009). The resolution of additionality, leakage and permanence issues is critical for acceptance of REDD and terrestrial sequestration in a post-2012 climate agreement; the identification of a pre-agreement

[2] For example the Voluntary Carbon Standard (http://www.v-c-s.org)

baseline against which deforestation/degradation reductions can be evaluated (Karsenty, 2008) is of equal importance. There are benefits that are unique to carbon sequestration activities, despite the fact that they are not permanent. To achieve these benefits, policies must ensure accurate value of temporary carbon sequestration and minimizing costs associated with transactions (Marland and Marland, 2009).

WELL-INTENTIONED POLICIES DO NOT NECESSARILY LEAD TO GOOD PRACTICES

Scientific information is lagging behind the desire to craft robust terrestrial carbon sequestration policies; some argue that there are too many uncertainties to proceed. For example, conservation tillage is one of the largest potential sources of greenhouse mitigation within the agricultural sector (Smith *et al.*, 2008) and, coupled with associated declines in fuel use, could make an immediate, substantial contribution to offsetting and reducing GHG emissions (Kimble, 2004; Paustian *et al.*, 2004). However, the implementation of reduced- or no-tillage practices does not always lead to significant increases in carbon stocks (Ussiri and Lal, 2009; Blanco-Canqui and Lal, 2008).

In some cases, depletion of soil carbon stocks at depth offsets gains in surface soils; the mechanism driving this process is not well-understood (Angers and Eriksen-Hamel, 2008; Baker *et al.*, 2007). There is also uncertainty about how practices that sequester carbon impact local climate through albedo and water balance (IPCC, 2007c); practices that lead to reduced GHG concentrations could promote local warming (Chapin *et al.,* 2008). Practices that sequester carbon could also lead to increased N_2O (such as fertilization to enhance carbon inputs), or CH_4 (e.g. flooding to preserve organic soils; see Box 2) (Schlesinger, 2000). The contribution of erosion to the depletion of soil carbon stocks and the fate of eroded carbon are additional, important uncertainties (Berhe *et al.*, 2007). Finally, disturbances are stochastic and often unpreventable processes that can lead to carbon losses (Smith, 2005), and ecosystem and socio-economic feedbacks (i.e. leakage, unintended consequences) are capable of undermining the intended benefits of forestry and agricultural sequestration projects (Jack, Kousky and Sims, 2008).

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LAND TENURE AND GOVERNANCE ISSUES COMPLICATE POLICY IMPLEMENTATION

Smallholder households represent a serious challenge for documenting carbon sequestration (Coomes *et al.*, 2008). Aggregation across a variety of landowners increases monitoring transaction costs, implying that the cost-effectiveness of carbon sequestration projects conflicts with poverty alleviation goals (Jack, Kousky and Sims, 2008; Lipper and Cavatassi, 2004). Pastoralists occupy substantial portions of the land area in many parts of the world, with the potential to sequester carbon in grasslands. However, pastoralists are often socially marginalized and with insecure land tenure rights, making it very difficult for participation in carbon markets (Neely *et al.*, 2009). In many of the places identified as having low-cost sequestration options, a large percentage of people make their living from the land. Compensation for foregoing land development could be financially beneficial, but may be of limited long-term development value. Uncertainty about land tenure among smallholders and weak institutions are key issues that discourage potential participants from adopting carbon sequestering practices (Greig-Gran, Porras and Wunder, 2005). Furthermore, practices that sequester carbon are not inherently coupled with other environmental benefits. For example, Nelson *et al*. (2008) found that in the northwestern part of the United States of America, sequestration policies did not necessarily achieve forest conservation goals and none of the conservation policies studied sequestered carbon. Similarly, the CDM has not yet led to forestry mitigation that successfully fosters adaptation to climate change (Reyer, Guericke and Ibisch, 2009).

SYSTEMS FOR DOCUMENTING CARBON STOCK CHANGES HAVE NOT BEEN AGREED UPON

Methods for analysing soil carbon concentration of a given sample are well established and easily carried out with high precision and minimal analytical error (Spark, 1996). However, soil carbon stocks vary as a function of soil texture, landscape position, drainage, plant productivity and bulk density, all of which vary spatially, and create heterogeneity that makes it difficult to quantify changes in soil carbon stocks over time (VandenBygaart, 2006; Robertson *et al.,* 1997; Cambardella *et al.,* 1994). Sampling error can be large and "the cumulative effects of managing small net sinks to mitigate fossil-fuel emissions will have to be understood, analyzed, monitored, and evaluated in the context of larger, highly variable, and uncertain sources and sinks in the natural cycle" (Houghton, 2006). Thus, the main challenge in documenting plot-level changes in soil carbon stocks is not in measuring carbon, but rather in designing an efficient, cost-effective sampling and carbon stock estimation system. Given higher rates of soil carbon sequestration, relatively low initial amounts of soil carbon, and modest spatial variability, the standard approach for a project – sampling and then future re-sampling of soil cores – would still require collection and analysis of dozens of soil samples to detect changes within a given field over a five- to ten-year time period that might be used for verification in an agricultural offset project (Conant and Paustian, 2002b; Yang *et al.,* 2008). Quantifying soil carbon changes at national or regional scales requires much more modest sampling densities (Makipaa *et al.,* 2008; Saby *et al.,* 2008), but such sampling precludes the possibility of attributing carbon credits to a particular practice or plot of land.

Practice-based estimates of soil carbon sequestration

One common approach to assessing changes in soil carbon stocks is to use information synthesized from previously published studies on how changes in management practices impact soil carbon stocks. Offsets can be verified by monitoring agronomic practices (e.g. monitoring no-tillage by surveying residue coverage on the soil surface). Such verification is already an established practice for other conservation programmes and can be relatively inexpensive. Syntheses of existing field experiments (Ogle, Breidt and Paustian, 2005) provide empirical estimates of the average soil carbon change for a particular practice within a broad region (see Figure 3). However, studies of management impacts on soil carbon stocks are so sparse that to rely on them for sequestration rates for a specific farm or group of farms in a given region (which are unlikely to be well represented by published studies) will lead to substantial uncertainty. This uncertainty is difficult to quantify using statistical methods with limited data. Moreover, the rates are typically based on relative changes in soil carbon stock changes, which could differ from the actual rates if there are other environmental drivers, such as climate change, that are also contributing to significant changes in soil carbon stocks. If uncertainty is high, permitted soil carbon offsets may be substantially discounted relative to estimated carbon sequestered, in order to limit the risk that the offsets do not represent real reductions in CO_2 emissions to the atmosphere (VCS, 2008). Another limitation of a broad practice-based approach is that it is economically inefficient (Antle *et al.*, 2003). Because of heterogeneity in the response of soils to specific management practices (due to differences in soils, climate conditions, land-use history), broadly based payments by practice will overcompensate poorer performance, and undercompensate better performance (hence disincentivizing their participation). Thus, even if the practice-based credit was an accurate estimate for the average performance within the region, the actual benefits achieved would be overestimated, and this inefficiency would increase as a function of the degree of spatial heterogeneity in soil response (Antle *et al.*, 2003). An estimation system that can account for more of the local variability in soil responses to a particular management practice will increase the economic efficiency of the mitigation policy, and provide a better estimate of the actual mitigation benefits achieved.

Combining measurement with mechanistic modelling

Terrestrial soil carbon offsets can be quantified using a mechanistic ecosystem model. A dynamic system comprised of a measurement database that is updated as new measured terrestrial soil carbon offset data become available could integrate measurements with state-of-the-art knowledge about ecosystem function, and enable the up-to-date calculation of model uncertainty estimates using established statistical methods (Ogle *et al.*, 2007). A system that combines measurement of soil carbon with models would have a number of unique benefits not possible with modelling or measurement alone. Systems that discount or withhold reserve credits to account for uncertainty, such as the Voluntary Carbon Standard, could use uncertainty derived from the model analysis associated with a particular offset activity to determine reserve requirement.

These systems would have the flexibility of a model-based approach, being able to account for all types of terrestrial offsets, unlike the measurement approach that is likely to have gaps, but would be reliable because the associated uncertainty is determined from on-the-ground observations. As a system, such a modelling-measurement approach would be robust because it would be continually updated as new sample data are made available, and it could be used to direct sampling towards those areas where uncertainty is greater relative to offset activity. Such systems could also potentially encourage more

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innovation by agricultural producers because new measurements would be incorporated from the latest management options, while using the model to allow all producers to receive credit from the latest innovations without necessarily requiring new measurements on each farm. Finally, a combined system could make use of published information on how other factors (like global change, widespread land-use changes, changes in land use prompted by terrestrial soil carbon offset programmes, etc.) affect soil carbon stocks both on- and off-site, to account for shifting baselines, additionality and leakage.

Data on management impacts on carbon stocks are limited in developing countries

Systems that integrate measurement and mechanistic modelling require robust sources of data that reflect the range of potential management practices. A variety of efforts are under way across the developed world to build up, test and implement such systems. However, all syntheses document that, in the developing world, observations of management-induced changes in soil carbon stocks are relatively rare (Conant, Paustian and Elliott, 2001; Smith *et al.*, 2006). Lack of accurate information can lead to greater uncertainty in estimates of soil carbon stock changes, and could result in climate-driven bias because developed country studies are more common in temperate regions. More importantly, practices that could be most beneficial risk being excluded from schemes to encourage carbon sequestration because the practices are not widely familiar to the scientists from the developed world, and to policy-makers who develop quantification tools. This paucity of data from developed countries presents a challenge to the creation of robust accounting systems that offer the same utility for quantifying soil carbon sequestration in developed and developing countries.

CHAPTER 5

The way forward

FOUNDATIONS FOR SOUND POLICIES

Current yields and economic returns can often be maximized by practices that boost forage harvest, deplete soil nutrients and reduce the long-term productive capacity of grassland systems. Indeed, economic pressures to "adopt unsustainable practices as yields drop" in response to a changing climate, "may increase land degradation and resource use" (IPCC, 2007d). This fact should further motivate support for policies and programmes that encourage the implementation of sustainable grassland management practices. Identifying and understanding situations in which short-term interests in harvest trump long-term interests in maintaining productive capacities, and developing technical solutions that involve research, education and technical assistance in implementing sustainable practices, should be a top priority. A key challenge is the large number of smallholders and pastoralists who may be among the hardest hit by climate change (FAO, 2009). Their challenge is often exacerbated because uncertain land tenure discourages investments that pay dividends in the long term. Thus, efforts to spread knowledge on sustainable grassland management practices are essential for ensuring their successful implementation and must address tenure-related motivations to implement sustainable practices.

Not all categories of producers have the same potential for implementing sustainable land management practices, and some producers will benefit more and sooner than others. Development–mitigation–adaptation strategies must be evaluated within the framework of local environmental conditions, institutions and capacities. Priority should be given to investments in sustainable land management practices that:

- show strong evidence of enhancing near- and longer-term productivity and profitability for farmers and pastoralists;

- offer opportunities to enhance production, mitigate GHG emissions and enable adaptation to climate change;
- develop incentives that foster sustainability of existing resources – soil, water, air, labour, etc.;
- rehabilitate lands that can be improved at modest cost, and adopting low-tech changes in management practices;
- support research and education on best practices for maintaining fertility and production; and
- align with existing investment programmes.

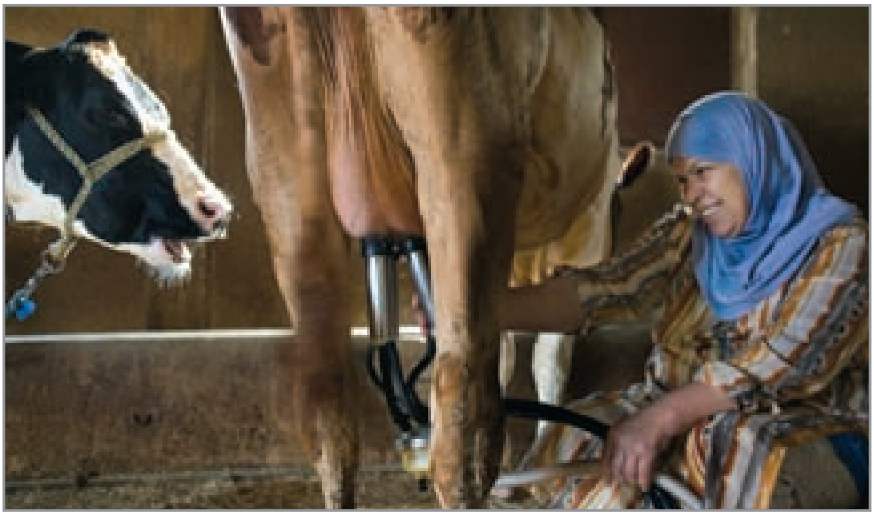
Despite win–win situations in which practices that sequester carbon also lead to enhanced productivity and substantial biological potential to sequester carbon in grasslands, policies to encourage adoption of practices that sequester carbon in grasslands lag behind policies for forest and agricultural lands. Like forestry and agricultural sequestration, policies that promote carbon sequestration in rangelands could form an important part of a "no regrets" climate strategy. This is particularly true for practices that promote increased primary productivity or livestock production and practices that arrest rangeland degradation. In addition to sequestering carbon, implementing practices that sequester carbon can help to achieve the strategic objectives of the UN Convention to Combat Desertification: improving livelihoods, enhancing productivity and generating global benefits. Reducing emissions from grassland degradation is not only likely to pay dividends in maintaining carbon stocks, but also in sustaining the livelihoods of people making a living from grasslands.

GRASSLAND CARBON SEQUESTRATION IN CONTEXT

Much of the world's grassland, a disproportionately large share of the degraded grassland and a majority of grassland sequestration potential is found in the developing world. More importantly, the fate of large portions of the populations in these areas is intimately tied to livestock production systems directly dependent upon grasslands. Sustaining productivity and rehabilitating degraded grassland systems are crucially important to people right now. It is also clear that there are synergistic effects with other development agendas. For example, Kandji and Verchot (2007) point out several ways in which developing countries in semi-arid East Africa will be adversely impacted by climate change and the relationship of those impacts to the Millennium Development Goals. The relevant goals are: reduce hunger and poverty (Goal 1) by reducing vulnerability to extreme events; ensure environmental sustainability (Goal 7) by rebuilding ecosystem carbon stocks and restoring ecosystem processes; and build a global development partnership (Goals 8) while enhancing the ability for governments to invest in key socio-economic sectors. Synergies between environmental, development and agricultural activities indicate opportunities for engagement from multiple sectors.

RESEARCH PRIORITIES

A key barrier to identifying priority investments is lack of knowledge on the impacts of grassland management in most of the developing world. Despite a large estimated potential in the developing world, lack of direct observations makes these estimates highly uncertain (Conant and Paustian, 2002a; Ogle, Conant and Paustian, 2004). Moreover, best management practices are typically based on those identified in other regions, limiting the breadth of management alternatives and possibly overlooking those



that could do more to build or rebuild soil carbon stocks and enhance productivity. Efforts to build capacity while enhancing environmental benefits, such as the participatory practice capture used by the World Overview of Conservation Approaches and Technologies (WOCAT), can simultaneously facilitate identification and implementation of best practices. Building soil carbon stocks through the implementation of improved/more sustainable management practices is just one component of developing more productive and efficient livestock production systems. Increasing livestock production could lead to greater CH_4 emissions, but improving feed quality by enhancing pasture management to produce forage with more balanced quality (Leng, 1993) could concurrently sequester carbon, and increase milk or meat production. If implemented in coordination with grazing practices that encourage consumption of a quality, mixed diet, CH_4 emissions per unit product could even decline. Improved grassland management can facilitate better breeding: reducing the number of replacement heifers, reaching slaughter weight at an earlier age, increasing milk production, bringing higher pregnancy rates, etc. This in turn could reduce GHG emissions per unit product, despite the fact that none of the practices mentioned above directly reduce emissions (Boadi *et al.*, 2004). A systems perspective is therefore crucial: research to assess carbon sequestration alone could miss important interactions with factors that control ruminant CH_4 emissions. This latter represents one of the largest sources of GHGs in developing countries.

Successful pilot projects carried out in collaboration with national scientists, grassland managers and development actors will play a key role in demonstrating the feasibility of new practices. At the same time, pilot projects are necessary to extend and divulgate information on the efficacy of grassland management practices as a mitigation strategy. Understanding the institutional requirements and testing carbon accounting procedures are crucial next steps for legitimizing mitigation through grassland management. Investing in pilot projects will engage community leaders, farmers and other resource users in programme development, and build up technical, organizational and human capacities (Pender *et al.*, 2009). An important component of a pilot programme consists of the conduct of desk reviews and collection of additional information on current and projected GHG emissions from other grassland projects and pilot studies. Outputs from this work built around a series of pilot study programmes could include:

- a comprehensive database of estimates of greenhouse emission factors by region, and a complete grassland emission inventory;
- a focus on documenting carbon sequestration responses for areas or practices that are understudied;
- an analysis of different global and regional scenarios for grasslands under different carbon constraints (different policy measures and prices for carbon), financing and crediting arrangements and the development of supporting models and tools;
- an analysis of the marginal costs of carbon sequestration in grasslands driven by changes in management practices, together with a detailed description of their implications for food security and livelihoods;
- policy and technical guidance for Nationally Appropriate Mitigation Actions that may affect grassland production and food security; and
- scientific underpinning in support of international (post-Kyoto) agreements on climate change.

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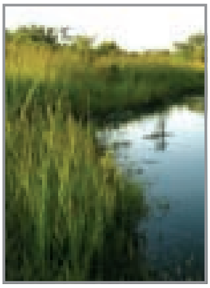
Policy brief

Pastoralists

Playing a critical role in managing grasslands for climate change mitigation and adaptation



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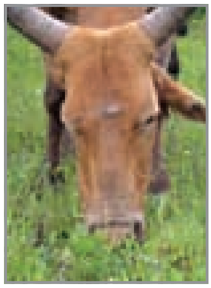

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GRASSLANDS REPRESENT THE MAJORITY OF THE WORLD'S AGRICULTURAL AREA AND HOLD 20 PERCENT OF THE WORLD'S SOIL CARBON STOCK

Grasslands, including rangelands, shrub land, pasture land and cropland sown with pasture, trees and fodder crops, represent 70 percent of the world's agricultural area.

GRASSLANDS ARE AN IRREPLACEABLE SOURCE OF LIVELIHOODS AND FOOD SECURITY FOR THE POOR

Poverty and economic marginalization often characterize the human communities managing grasslands. Livestock keeping is a source of income and basis for food security for more than 1 billion people – or one-third of the poor in rural areas – and is also the only potential source of income that can be derived from many grassland areas (see Figure A). In addition, grasslands are a source of goods and services such as wild food, energy and wildlife habitat. They also provide carbon and water storage, recreation and watershed protection for many major river systems.

MUCH OF THE WORLD'S GRASSLANDS ARE IN A STATE OF DEGRADATION

Globally grassland degradation is estimated to be 20–35 percent. Because livestock is the fastest growing agricultural sector – making up over 50 percent of agricultural GDP in many developing countries – pressure on the land has increased in order to meet meat and milk demand. As a result of inappropriate grazing management practices, large parts of the world's grasslands have been degraded.

ACCORDING TO THE IPCC, IMPROVING GRASSLAND MANAGEMENT AND REVERSING DEGRADATION OFFER THE MOST IMPORTANT TECHNICAL MITIGATION SOLUTIONS IN AGRICULTURE

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 and restoration of ecosystem services. Many management techniques intended to increase forage production have the potential to increase soil carbon stocks, thus sequestering atmospheric carbon in soils. Improved grazing management can lead to an increase in soil carbon stocks by an average of 0.35 tonnes C ha^{1} yr^{-1} but under good climate and soil conditions improved pasture and silvopastoral systems can sequester 1–3 tonnes C $ha^{-1}yr^{-1}$. It is estimated that 5–10 percent of global grazing lands could be placed under C sequestration management by 2020 (See Figure B).

GRASSLAND MANAGEMENT PRACTICES THAT REDUCE EMISSIONS ALSO ENHANCE ADAPTATION

Well-managed grasslands provide multiple co-benefits that are critical to adaptation. Risks associated with prolonged drought periods and unreliable rains can be offset by the increased water infiltration and retention associated with organic matter accumulation in the soil. Moreover, this will improve nutrient cycling and plant productivity and, at the same time, enhance the conservation and sustainable use of habitat and species diversity. Grassland management is thereby a key adaptation and mitigation strategy for addressing climate change and variability.

GRASSLANDS CAN BECOME A BRIGHT SPOT THROUGH SYSTEMS MANAGEMENT

Grazing practices can be used to stimulate diverse grasses and the development of healthy root systems; feed both livestock and soil biota; maintain plant cover at all times; and promote natural soil forming processes. Grazing practices that ensure adequate plant recovery before re-grazing will enhance soil and biomass carbon, capitalize on animal based nutrients and offset ruminant methane emissions.

EFFORTS TO INCREASE THE RESILIENCE OF GRASSLAND MANAGEMENT SYSTEMS AND SUPPORT LIVESTOCK KEEPERS MUST BEGIN NOW

Because yield reductions under drought, heat stress, floods and other extreme events will be the most consequential negative impacts of climate change, efforts to adapt to a changing climate should focus on increasing resilience of ecosystem processes through management systems and the policies that support these. This will also require addressing key political constraints including land tenure.

POST COPENHAGEN AGRICULTURAL PRIORITIES WILL REQUIRE INTEGRATED ADAPTATION AND MITIGATION EFFORTS FOCUSED ON LIVESTOCK KEEPERS, GRAZING MANAGEMENT AND FORAGE PRODUCTION PRACTICES

Critical components required, with or without Copenhagen agreements, include:

- raising awareness at the local level about the potential impacts of climate change;
- implementing grazing management systems that build soil carbon, enhance biological communities, re-establish effective water cycles, and manage livestock-based nutrients; and
- promoting soil cover of grasses, legumes and multipurpose trees to enhance livestock productivity.

Understanding and accounting for carbon and nitrogen flows will be instrumental in capitalizing on the full potential of grassland systems for adaptation and mitigation. Climate change will demand the sustainable stewardship of our natural resource base that has been called for over the last several decades.

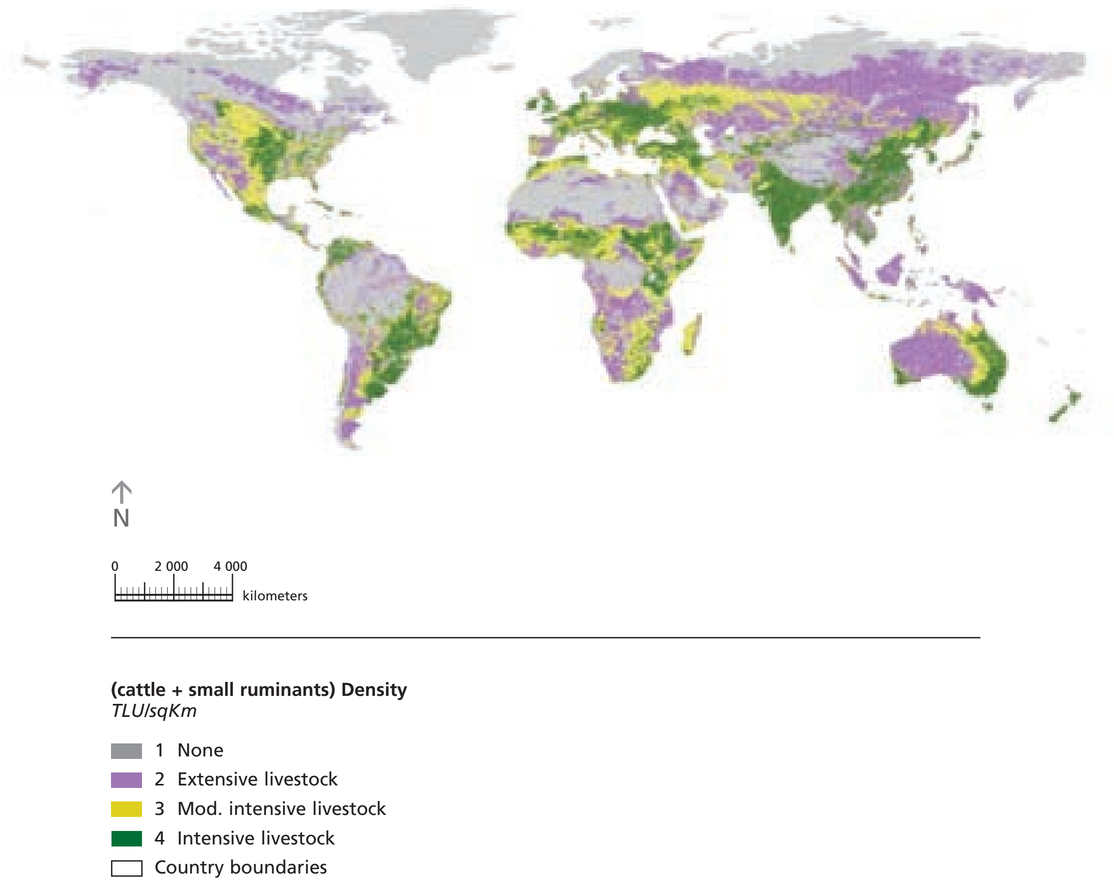
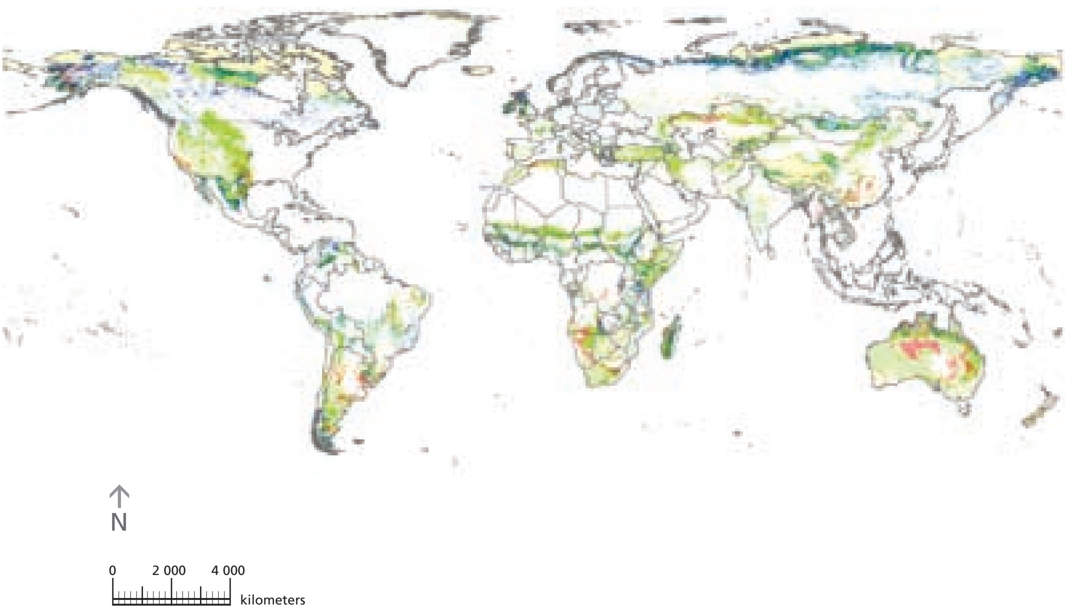


FIGURE A: Livestock presence intensity

Source: FAO LADA Mapping Land Use Systems at global and regional scales for Land Degradation Assessment Analysis, Nachtergaele and Petri, 2009



Topsoil SOC change
kg/sq m

- > 0.1
- 0.051 – 0.1
- 0.026 – 0.05
- 0.01 – 0.025
- 0 – 0.01
- 0
- -0.01 – 0
- < -0.01
- country boundaries

FIGURE B: **Potential soil organic carbon sequestration in grasslands**
Geographic projection. 30 arc seconds resolution at the equator

Source: Carbon status and carbon sequestration potential in the world's grasslands. Petri, M., Batello, C., Villani, R. and Nachtergaele F., 2009

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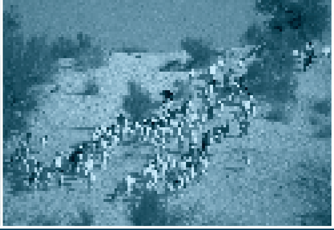

Challenges and opportunities for carbon sequestration in grassland system
A technical report on grassland management and climate change mitigation

Practices that sequester carbon in grasslands can enhance productivity, and policies designed to encourage these practices could lead to near-term dividends in greater forage production and enhanced producer incomes.

This report reviews the current status of opportunities and challenges for grassland carbon sequestration and identifies components that could foster the inculsion of grasslands in future climate agreements to enhance longer term adaptation to climate variability. It includes a policy brief to assist policy-makers in their development plans.

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