IV.16 Supporting Evidence for Greenhouse Gas Mitigation in Agriculture

Julian Dumanski, Raymond L. Desjardins, Rattan Lal, and Mark Rosegrant

The options for GHG mitigation discussed in the four Boxes IV.16, IV.17, IV.18 and IV.19 are agricultural systems with the highest potentials: agroforestry, rangeland management, zero tillage, and livestock production. Undoubtedly, other options may provide benefits in local situations, but recent evidence indicates that these farming systems provide the best opportunities.

Box IV.16 (Contributed by L. Verchot)

Agroforestry systems in the humid tropics include various types of tree-based production systems. Research in these areas (Palm et al. 2002) showed that conversion of primary tropical forests to cropland or grassland resulted in the loss of about 310 Mg C ha^{-1}, with managed or logged forests having only about half the C stocks of primary forests. Agroforestry systems contained 50–75 Mg C ha^{-1} compared to row crop systems with < 10 Mg C ha^{-1}. These results show that converting row crops or pastures to agroforestry systems can greatly enhance the C stored in above and below ground biomass. [Literature referred to in Sect. III.5.5.(γ) however cautions against too big expectations.]

Agroforestry also compares well with other land uses with respect to other GHGs. In Sumatra, a jungle rubber system had lower N_2O emissions than a primary forest, but also lower CH_4 uptake (Tsuruta et al. 2000). However, agroforestry systems such as multi-storey coffee with a leguminous tree shade canopy had N_2O emissions five times higher than open-grown coffee and about half the CH_4 uptake (Verchot 2007). In Peru, agroforestry systems (multistrata coffee and a peach palm plantation) with leguminous cover crops had lower N_2O emissions than both intensive and low-input agriculture and similar emissions to a nearby secondary forest (Palm et al. 2002). Soil uptake of

J. Dumanski (✉)
Retired from Agriculture and Agri-Food Canada and World Bank, Ottawa, ON, Canada
e-mail: jdumanski@rogers.com

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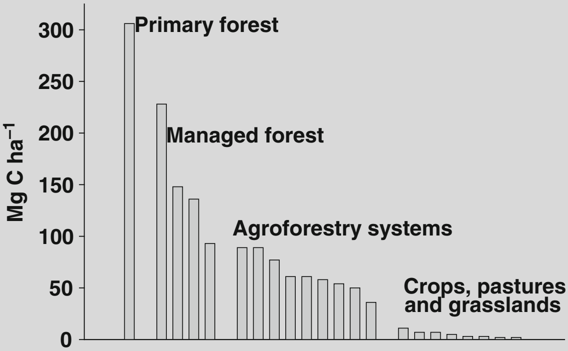
CH_4 was similar to other land use systems, with the exception of an intensive agriculture site, which became a net source to the atmosphere.



Agroforestry also has an important carbon sequestration role to play in the sub-humid tropics. Improved tree-based fallow rotations between cereal crops and tree-legume fallows have high potential to sequester C in both the aboveground biomass and the soil. Belowground C storage in these systems represents the potential for long-term C storage, as long as trees remain in the rotation, but the storage capacity is largely dependent upon soil texture and total rainfall. Coppicing fallows are newer, but follow similar trends. While these systems are cut frequently, the average aboveground carbon stocks exceed stocks in degraded land, cropland or pastures. Nitrous oxide emissions following the leguminous tree fallows was found to be almost 10 times that of unfertilized maize (Chikowo et al. 2003) but these levels were still extremely low in comparison to the amount of C stored.

Restoration of degraded land using improved tree fallows has the potential not only to sequester significant amounts of C from the atmosphere, it also offers opportunities for improving rural livelihoods by turning unproductive land into productive land that can produce food, wood and other tree products, and generate income. Typically, there are trade-offs between carbon stored and on-farm profitability, and while high carbon and high profit land uses have not yet been identified, several no regret options with medium to high profit and medium carbon stocks are already available, and could be implemented as a component in climate change mitigation schemes.

Box IV.17 (Contributed by G.E. Schuman and J.D. Derner)

Rangelands have a large potential for GHG mitigation because of the large global land area represented, even though the increase of soil carbon per unit of land is small (estimated as 0.02–0.20 Mg C ha^{-1} $year^{-1}$; Lal 2000). Globally, rangelands are estimated to contain 10–30% of the global SOC (Scurlock and Hall 1998). Schuman et al. (2001) estimated that improved management on 113 Mha of poorly managed rangelands in the US could sequester an additional 11 Tg of C annually. In addition, they estimated that the loss of 43 Tg C $year^{-1}$ could be avoided through the continued use of sustainable grazing practices, conservation of undisturbed native rangelands, and restoration of marginal croplands to perennial grasslands.

Soil C storage in rangelands is influenced by climate, biome type, rangeland management including grazing, N inputs and restoration, and environmental conditions such as drought, and climate change. Grazing management can influence rates of soil C sequestration by facilitating physiological breakdown, soil incorporation and rate of decomposition of plant materials. Grazing on a shortgrass steppe increased SOC in the top 30 cm of the soil compared to adjacent non-grazed exclosures by 0.12 and 0.07 Mg C ha^{-1} $year^{-1}$ for moderate and heavy stocking rates, respectively (Derner et al. 1997, 2006; Reeder et al. 2004). Also, grazing at light or heavy stocking rates in a northern mixed grass prairie increased SOC in the top 30 cm of the soil by 0.30 Mg C ha^{-1} $year^{-1}$ compared to non-grazed exclosures (Schuman et al. 2001). Improvement of soil N status in rangelands can be achieved by interseeding legumes into these systems. For example Mortenson et al. (2004, 2005) reported that interseeding of alfalfa (*Medicago sativa* ssp. *falcata*) into northern mixed grass rangelands significantly increased total forage production and increased SOC from 0.33 to 1.56 Mg C ha^{-1} $year^{-1}$. The use of legumes to enhance the N status of the soil can be achieved without the risk of increased N_2O emissions (Schuman et al. 2004). However, reduced SOC sequestration can be expected with longevity in grazing practices (Derner and Schuman 2007), consistent with other observations that ecosystems reach a new "steady-state" normally at levels lower than the original.

Climate, especially precipitation, can significantly impact C sequestration in rangelands, with SOC generally increasing with increasing precipitation; SOC in mesic rangelands can be 2–3 times higher than those in semi-arid rangelands (Derner et al. 2006). However, changes in precipitation and droughts may change rangelands from sinks to sources of CO_2. Ingram et al. (2008) reported that several years of severe drought resulted in a loss of SOC from soil of a northern mixed grass prairie that had been storing SOC for the previous 11 years. Also, C sequestration rates (in the top 30 cm of soil) have been shown to go from positive to negative with approximately $>$440 mm of precipitation (Derner and Schuman 2007).

Box IV.18 (Contributed by P.L. De Freitas and J.N. Landers)

Zero tillage (ZT) involves direct placement of seeds into the residues of the previous crop. However, refined procedures of ZT, called integrated ZT (Conservation Agriculture), includes maintenance of crop rotations, integrated pest and weed management, use of modern varieties and cultivars, careful and selective crop fertilization systems, and many other conservation technologies (De Machado and De Freitas 2003). The collective impacts of these technologies are increased soil carbon sequestration, reduced emission of non-CO_2 gases, and improved economic and environmental sustainability of agriculture in the tropics and sub-tropics. By removing CO_2 from the atmosphere, ZT technologies reduce the impacts of climate change.
Based on Brazilian conditions, soil carbon sequestration in grain crops grown under ZT can be approximately 350 kgC $ha^{-1}year^{-1}$ to a depth of 20 cm in tropical savannahs, and up to about 480 kgC $ha^{-1}year^{-1}$ in sub-tropical regions (Bayer et al. 2006). Considering the area already under ZT in Brazil, this can result in carbon sequestration of 29–40 Tg $year^{-1}$. However, considering the growth potential of ZT in Brazil, up to about 100 million hectares, and including the potential for production of ethanol and biodiesel, this could result in C sequestration in the order of 130–175 Tg of CO_2 $year^{-1}$ (De Freitas et al. 2007). This potential corresponds to 3–13% of all CO_2 currently emitted by deforestation and land use change (estimated at 1.4–4.3 Pg of CO_2). In temperate regions, ZT has been shown to remove small amounts of CH_4 from the atmosphere, but N_2O emissions are sometimes higher (Six et al. 2002).

Other benefits of ZT technologies are reduced emissions of GHG to the atmosphere, which accrue because of reduced use of fossil fuels for crop production, reduced use of chemical fertilizers and reduced N_2O emissions, reduced use of pesticides, and reduced soil erosion. Also, by capturing the synergy with other conservation technologies, ZT along with crop rotations promotes reduced CH_4 emissions in rice production, and CH_4 reductions in livestock enterprises, when combined with improved pasture and fertilizer management. In addition, ZT technologies have been used successfully to reduce residue burning in sugar cane production, thus reducing GHG emissions and air pollution (De Luca et al. 2008). The impacts of these, however, are considerably lower than those obtained through carbon sequestration (Verchot 2007).

Integrated ZT has been shown to improve the economic sustainability of both large and small holder agriculture. It has also been shown to considerably reduce off-farm externalities, such as soil erosion and silt control, public expenditures for infrastructure maintenance. It improved water filtration and aquifer recharge, local biodiversity and mitigation of drought. Some estimates for Brazil show that through the integration of crop and cattle enterprises under combined ZT and conservation principles, it may be possible to increase grain, fibre and meat production in Brazil to meet market demands for the next 20 years or more without further deforestation in frontier areas (Landers and De Freitas 2001).

Box IV.19 (Contributed by P. Gerber and H. Steinfeld)

The livestock sector is characterized globally by two contrasting production systems, (a) the rapidly growing industrial systems of pig and poultry production, (b) extensive and backyard production, mostly ruminants. Livestock production is an important form of income diversification, but for the very poor and those populations without land resources, it is often the only source of income. People living in marginal environments would not survive without their animals.

Livestock production often imposes a substantial environmental footprint, affecting climate, water resources and biodiversity in major ways. When taking into account the entire livestock commodity chain, from land use and feed production, to livestock waste and product processing, livestock production contributes about 18% of the total anthropogenic GHG emissions. Along the animal food chain, the main sources of emissions are:

- Land use and land use change: 2.5Gt CO_2e; including deforestation and conversion of natural grasslands to pasture and feed crops in the tropics and sub-tropics (CO_2) and carbon release from soils during cultivation (CO_2).
- Feed production: 0.4 Gt CO_2e, including fossil fuel used in manufacturing fertilizers (CO_2) and chemical fertilizer application on feed crops (N_2O, NH_3).
- Animal production: 1.9 Gt CO_2e, including enteric fermentation from ruminants (CH_4) and on-farm fossil fuel use (CO_2).
- Manure management: 2.2 Gt CO_2e, mainly through manure storage, manure application and manure deposition (CH_4, N_2O, NH_3).
- Processing and international transport: 0.03 Gt CO_2e.

Livestock related emissions are highest for beef and lowest for poultry, they are often diffuse and indirect, and occur at both the high and low end of the intensity spectrum. On average, extensive production has higher emissions per unit of output.

These high emission levels provide opportunities for GHG mitigation by the livestock sector, with often higher cost efficiency than in other sectors. Carbon-dioxide emissions can be limited by reducing deforestation, as well as by application of rangeland management practices such as: restoring organic carbon in cultivated soils, reversing soil organic carbon losses from degraded pastures, and sequestration through agroforestry. Improved livestock diets and better manure management can substantially reduce methane emissions, while careful nutrient management (i.e. fertilization, feeding and waste recycling) can mitigate nitrous oxide emissions and ammonia volatilization. Other opportunities, such as soil carbon in pastoral systems have not yet been exploited because of knowledge and institutional constraints but could potentially supply considerable offsets.

The use of biogas technologies can provide environmental benefits by redirecting emissions from manure management and reducing fossil fuel consumption, while simultaneously reducing on-farm expenses (e.g. from savings on energy bills, electricity trading). Already, private investors have used biogas within the framework of carbon trading projects within the CDM.

Global carbon trading will increase in the future, but two key constraints need to be overcome before significant benefits can be channeled to rural areas in developing countries (a) the rules of access must change, since these still do not credit developing countries for reducing emissions by avoiding deforestation or improving soil carbon sequestration, (b) the operational rules, with their high transaction costs for developing countries and small farmers and foresters in particular, must be streamlined.

Clean Development Mechanism (CDM) rules should encourage the participation of small farmers and community forest and agroforestry producers, and protect them against major livelihood risks, while still meeting investor needs and rigorously ensured carbon offset goals. This can be supported by:

- *Broadening the definition of afforestation and reforestation*. Agroforestry, assisted natural regeneration, forest rehabilitation, forest gardens, and improved forest fallow projects should all be eligible under CDM, because they offer low-cost approaches to carbon sequestration, while offering fewer social risks and significant community benefits and biodiversity benefits. Short-duration tree-growing activities should be permitted, with suitable discounting. Unfairly favoring large plantations should be avoided.
- *Promoting measures to reduce transaction costs*. Rigorous, but simplified procedures, as typified by the Chicago Climate Exchange, should be adapted to developing country carbon offset projects. Small-scale projects can benefit from simplified ways of determining baselines and monitoring carbon emissions. Small-scale agroforestry and soil carbon sequestration projects should be eligible for simplified modalities to reduce the costs of these projects. The permanence requirement for carbon sequestration should be revised to allow shorter term contracts, or contracts that pay based on the amount of carbon saved per year, which would avoid the need for "locking up" land in forest land uses for prolonged periods.

- *Establishing international capacity building and advisory services*. The successful promotion of livelihood enhancing CDM sequestration projects will require investment in capacity-building and advisory services for potential investors, project designers and managers, national policy makers, and leaders of local organizations and federations. Regional centers should be established to assist countries and communities involved in forest carbon trading. Institutional innovations can provide economies of scale and specialization. Companies or agencies can provide specialized business services for low-income producers to help them negotiate deals or design monitoring systems. Locally accountable intermediary organizations can manage projects and mediate between investors and local people.

Additional investment in advanced measurement and monitoring can dramatically reduce transaction costs. Measurement and monitoring techniques have been improving rapidly thanks to a growing body of field measurements and the use of statistics and computer modeling, remote sensing, global positioning systems, and geographic information systems, so that changes in stocks of carbon can now be estimated more accurately at lower cost.

References

Bayer C, Martin-Neto L, Mielniczuk J, Pavinato A, Dieckow J (2006) Carbon sequestration in two Brazilian Cerrado soils under no-till. Soil Till Res 86:237–345

Chikowo R, Mapfumo P, Nyamugafata P, Giller KE (2003) Mineral N dynamics, leaching and nitrous oxide losses under maize following two-year improved fallows on a sandy loam soil in Zimbabwe. Plant Soil 259:315–330

De Freitas PL, Martin-Neto L, Manzatto CV (2007) Solos: além de tudo, seqüestro de carbono [Soils: besides all, carbon sequestration]. In: Rev Agroanal, Fundação Getúlio Vargas, Rio de Janeiro, Brazil. Caderno Especial: Serviços ambientais no negócio agrícola [Special Anex: Environmental services in agribusiness] 2(4):E15–E16. www.agroanalysis.com.br/index.php?area=conteudo& esp_id=12& from=especial& epc_id=83

De Luca EF, Feller C, Cerri CC, Barthès B, Chaplot V, Campos DC, Manechini C (2008) Avaliação de atributos físicos e estoques de carbono e nitrogênio em solos com queima e sem queima de canavial. [Evaluation of physical properties and soil carbon and nitrogen stocks as affected by burning or green trash management of sugarcane] Rev Bras Ciênc Solo (Viçosa, Brasil) 32:789–800

De Machado PLO, De Freitas PL (2003) No till farming in Brazil and its impact on food security and environmental quality. In: Lal R, Hobbs P, Uphoff N, Hansen D (eds) Sustainable agriculture and the rice-wheat system. Marcel Dekker, New York, pp 291–310

Derner JD, Schuman GE (2007) Carbon sequestration and rangelands: a synthesis of land management and precipitation effects. J Soil Water Conservation 62:77–85

Derner JD, Briske DD, Boutton TW (1997) Does grazing mediate soil carbon and nitrogen accumulation beneath C_4 perennial grasses along an environmental gradient? Plant Soil 191:147–156

Derner JD, Boutton TW, Briske DD (2006) Grazing and ecosystem carbon storage in the North American great plains. Plant Soil 280:77–90

Ingram LJ, Stahl PD, Schuman GE, Buyer JS, Vance GF, Ganjegunte GK, Welker JM, Derner JD (2008) Grazing impacts on soil carbon and microbial communities in a mixed-grass ecosystem. Soil Sci Soc Am J 72:939–948

Lal R (2000) Soil management in developing countries. Soil Sci 165:57–72

Landers JN, De Freitas PL (2001) Preservação da vegetação nativa nos trópicos Brasileiros por incentivos econômicos aos sistemas de integração lavoura x pecuária com plantio direto. [Preservation of the natural vegetation in the Brazilian tropics by economic incentive to integrate crop/livestock ley farming with zero tillage adoption] In: Encontro Nacional da Sociedade Brasileira de Economia Ecológica–ECOECO 4. [Fourth National Meeting of the Brazilian Society for Ecological Economics], Belém, Brazil, Mesa Redonda 3–CDRom, np [Round Table 3–CDRom, no page reference]. www.ecoeco.org.br/conteudo/publicacoes/encontros/iv_en/mesa3/10.pdf

Mortenson MC, Schuman GE, Ingram LJ (2004) Carbon sequestration in rangelands interseeded with yellow-flowering alfalfa (*Medicago sativa* ssp. *falcata*). Environ Manag 33:S475–S48

Mortenson MC, Schuman GE, Ingram LJ, Nayigihugu V, Hess BW (2005) Forage production and quality of a mixed-grass rangeland interseeded with *Medicago sativa* ssp. *falcata*. Rangel Ecol Manag 58:505–513

Palm CA, Alegre JC, Arevalo L, Mutuo PK, Mosier AR, Coe R (2002) Nitrous oxide and methane fluxes in six different land use systems. Glob Biogeochem Cycl 16:1073

Reeder JD, Schuman GE, Morgan JA, LeCain DA (2004) Response of organic and inorganic carbon and nitrogen to long-term grazing of the shortgrass steppe. Environ Manag 33:S485–S495

Schuman GE, Herrick JE, Janzen HH (2001) The dynamics of soil carbon in rangeland. In: Follett RF, Kimble JM, Lal R (eds) The potential of US grazing lands to sequester carbon and mitigate the greenhouse effect. Lewis Publisher, Boca Raton, pp 267–290

Schuman GE, Ingram LJ, Parkin TA (2004) Nitrous oxide emissions from a northern mixed-grass rangeland interseeded with yellow-flowering alfalfa (*Medicago sativa* ssp. *falcata*). Society for Range Management Abstracts, Salt Lake City, Abstract #323, p 180

Scurlock JM, Hall DO (1998) The global carbon sink: a grassland perspective. Glob Change Biol 4:229–233

Six J, Feller C, Denef K, Ogle SM, De Moraes Sa JC, Albrecht A (2002) Soil organic matter, biota and aggregation in temperate and tropical soils—effects of no-tillage. Agronomie 22:755–775

Tsuruta H, Ishizuka S, Ueda S, Murdiyarso D (2000) Seasonal and spatial variations of CO_2, CH_4, and N_2O fluxes from the surface soils in different forms of land-use/cover in Jambi, Sumatra. In: Murdiyarso D, Tsuruta H (eds) The impacts of land-use/cover change on greenhouse gas emissions in Tropical Asia, Global Change Impacts Centre for Southeast Asia and National Institute of Agro-Environmental Sciences, IC-SEA. Bogor, Indonesia and NIAES, Tsukuba, pp 7–30

Verchot LV (2007) Opportunities for climate change mitigation in agriculture. A report to the UNFCCC Secretariat. Financial and Technical Support Programme. unfccc.int/files/cooperation_and_support/financial_mechanism/application/pdf/verchot.pdf