Environmental Development 19 (2016) 70–74

Contents lists available at ScienceDirect

Environmental Development

journal homepage: www.elsevier.com/locate/envdev

Grazing lands in Sub-Saharan Africa and their potential role in climate change mitigation: What we do and don't know

Eleanor Milne [a,*], Ermias Aynekulu [c], Andre Bationo [d], Niels H. Batjes [e], Randall Boone [a], Rich Conant [a], Jonathan Davies [f], Niall Hanan [g], Dana Hoag [a], Jeffrey E. Herrick [h], Walter Knausenberger [b], Constance Neely [c,i], Jesse Njoka [j], Moffatt Ngugi [b], Bill Parton [a], Keith Paustian [a], Robin Reid [a], Mohamed Said [k], Keith Shepherd [c], David Swift [a], Philip Thornton [k], Stephen Williams [a], Sue Miller [a], Ephraim Nkonya [l]

[a] *Colorado State University, USA*
[b] *USAID, USA*
[c] *ICRAF (World Agroforestry Centre), Kenya*
[d] *Alliance for a Green Revolution in Africa, Ghana*
[e] *ISRIC – World Soil Information, The Netherlands*
[f] *IUCN*
[g] *South Dakota State University, USA*
[h] *USDA-ARS, USA*
[i] *FAO, Italy*
[j] *University of Nairobi, Kenya*
[k] *CSDES, University of Nairobi, ILRI, Kenya*
[l] *IFPRI, USA*

A R T I C L E I N F O

Article history:
Received 2 February 2016
Accepted 8 June 2016

1. Introduction

In 2014, the USAID project ‘Grazing lands, livestock and climate resilient mitigation in Sub-Saharan Africa’ held two workshops, hosted by the Colorado State University, which brought together experts from around the world. Two reports resulted from these workshops, one an assessment of the state of the science, and the other an inventory of related activities in the region to date.. In this short communication we summarize the main points of the first report – The state of the science (Milne and Williams, 2015). A second report is in preparation.

The recent historical Paris Agreement aims to limit global warming to well below 2 °C, ideally below 1.5 °C. In order to achieve this, emissions reductions need to be accompanied by mitigation activities. The potential role of agriculture and land use in emissions reduction and mitigation has now gained recognition. Land based emissions are to be increasingly included in countries Nationally Determined Contributions (NDC's formally INDCs). In addition, initiatives such as the

* Corresponding author.

http://dx.doi.org/10.1016/j.envdev.2016.06.001

French 4/1000 initiative (which advocates an annual increase of organic matter in soils of 0.4%), highlight the potential role of soils in mitigation activities. Lal (2015) estimates that a 0.4% increase in soil organic carbon (SOC) to a depth of 30 cm could offset about 25% of anthropogenic greenhouse gas (GHG) emissions per year (using emissions from 2014).

Grazing lands are particularly important in this context as they account for an estimated 25% of potential carbon (C) sequestration in world soils (Follet and Reed, 2010), yet they have so far been grossly underrepresented in climate change mitigation strategies. Aside from mitigation potential, increasing C stocks in soils can have multiple benefits including improving water infiltration and storage, improving nutrient cycling, increasing land productivity and increasing below and potentially above ground biodiversity, hence improving livelihoods.

Sub-Saharan Africa is important to any consideration of global mitigation potential in grazing lands as it is home to approximately 23% of the world's poor, most of whom are dependent on livestock and therefore grazing lands (Thornton et al., 2002). Grazing lands in SSA are currently being lost due to land degradation, conversion to crop and urban land and other factors at an alarming rate. This threatens many traditional grazing systems which have been practiced for hundreds of years maintaining grazing land resources in often resource poor areas. There is an urgent need to evaluate the benefits of grazing lands in terms of ecosystem services including climate change mitigation.

2. Determinants of C sequestration potential in grasslands in SSA

The key determinants of C sequestration potential in grazing lands in SSA are climate (rainfall amount and regime) and soil type (Lal et al., 2015). The extent to which this potential is realized is determined by fire, drought and disease (both natural and human induced) and human activities such as land use conversion, grazing and land management practices and inputs from external sources (organic amendments, fertilizers, etc.). Removal of a large amount of aboveground vegetation, continuous heavy stocking rates, frequent human-ignited burning and other poor grazing management practices are important human-controlled factors that adversely influence grassland production and have also led to depletion of soil C stocks. However, good grazing land management that contributes to plant recovery, diversity of species, soil cover, enhanced organic matter, and functioning ecosystem processes (solar energy capture, biological communities) and cycles (nutrients, water) can potentially reverse historical soil C losses and sequester substantial amounts of C in soils. Supplemental inputs of water, nutrients and in some cases plant genetics can allow the natural potential to be exceeded.

3. Gaps in our understanding of the determinants of C sequestration potential

We understand the basic soil forming factors and how these govern C sequestration; however, our understanding of the following (which have high relevance to the situation in grasslands in SSA) is still poor:

- Phosphorus and the role it plays in C sequestration in grasslands, particularly the co-limitation of N and P in grasslands dominated by C4 species (as is often the case in SSA).
- The effect of ultraviolet radiation on the decomposition of litter and organic matter.
- The impact of termite activity on the amount and distribution of organic matter and C in soils.
- An understanding of shifts between shrublands and grasslands, the drivers of this change and the impact this has on above and below ground C stocks.
- Rate of C sequestration and saturation levels.

These gaps in our understanding could be narrowed in the next five years with targeted research. We believe that in terms of mitigation, efforts should be focused on those geographic areas with the highest C sequestration potential. However, it is also acknowledged that realistically, practical, social, economic and political considerations are likely to be the main drivers determining where activities take place.

4. The role of land management

Fertilization, fire management and the management of water all contribute to C sequestration in grazing lands in SSA. However, most of the potential sequestration would likely be the result of changes in species composition and production in response to these factors and grazing management. There is no consensus in the literature regarding impacts of grazing on C stocks or sequestration potential in SSA. In general it can be said that:

- In mesic environments sustained grazing pressure is likely to lead to land degradation (and therefore may cause soil organic carbon (SOC) to decrease)
- In dry areas with high rainfall variability, land degradation from sustained grazing may not be as apparent as grazing effects are overridden by rainfall effects
- Long-term studies on grazing/precipitation effects on SOC, particularly in rainfall variable areas in SSA, are needed.

Many management strategies which increase C stocks which benefit climate change mitigation, can also have adaptation benefits, leading to improved use of scarce resources such as water and manure. Equally, adaptive management systems may promote good land management in general with potential co-benefits for carbon and therefore climate change mitigation. This is an important consideration as many sectors in developing countries understandably prioritize adaptation with mitigation being a co-benefit.

Key data that would improve our understanding of C sequestration in grazing lands in SSA include information on the land management practices themselves (i.e., what they are and where they occur) and the effects of socio-economically and biophysically driven changes in land use and management on soil organic carbon (SOC) content, such as the occurrence of natural and human-ignited fires, within the various livestock production systems. Such landscape scale effects may be more easily considered now as high (250 m) resolution soil property maps, derived from digital soil mapping, have very recently become available for SSA (Hengl et al., 2015).

5. Monitoring

The costs and practical constraints associated with monitoring C in soils and biomass have long been a topic of debate and can be prohibitive when carrying out landscape scale assessments. In some cases the cost of demonstrating the change in C stocks in soils to the required accuracy and precision may exceed the benefits that accrue from the increase in stocks (IPCC, 2006). Although infrared spectroscopy, a technique which can correlate the absorption of light with C content, significantly reduces the analytical cost and speed of measuring soil C, costs incurred in soil sampling and preparation still form the largest component of the total monitoring cost (Aynekulu et al., 2011). Reward for known 'good C practice', validated by limited monitoring of C stocks, may be a more realistic way forward.

Although soil C is a key soil quality indicator, it alone does not provide sufficient information to guide wise use of land resources, and therefore standalone C measurement systems will have limited value, especially given the large resources required for field sampling and soil preparation. In most cases it will be more efficient to embed C measurement within broader land health surveillance schemes. This has recently been acknowledged by the Sustainable Development Goals (SDG's) in SDG 15.3 and the United Nations Convention to Combat Desertification (UNCCD) (UNCCD, 2015). Both establish 'Land Degradation Neutrality', (LDN) as an aspiration/goal for the coming decades. Currently identified indicators of LDN include land cover/use, land productivity and soil organic carbon. This creates potential momentum for monitoring soil C and taking more proactive measures to boost it.

6. Modeling

Grazing lands typically cover vast areas. Estimating carbon stocks and stock changes over such areas demands some kind of modeling to scale up point-based measurements and/or to estimate changes over time. Ecosystem models are capable of representing the multiple interactions between biophysical processes and management at a landscape scale. Examples of broad-scale application to situations in Africa, including grazing lands, are limited but increasing in number (Conant and Paustian, 2002; Ardo and Olson, 2003; Batjes, 2004; Kamoni et al., 2007). However the use of models is limited by a lack of information on biophysical aspects of grazing lands in SSA, data for model parameterization and validation and a lack of information on management practices at the appropriate scale, and their effects on carbon dynamics in different soils and climates.

7. Recent estimates of C content and sequestration potential in grazing lands in SSA

Using continental scale data sets for livestock production zones, climate and soil types, Batjes (2015) used a GIS-based mapping approach to assess regional differences in SOC reserves for grazing lands in SSA Africa. This approach indicated that, as a reflection of regional differences in the type and intensity of the soil forming factors of climate, parent material, relief, organisms (notably humans) and time (Jenny, 1941), and main drivers of recent soil change (e.g., land use and climate change), for a given livestock production system, the area-weighted SOC content increases as annual rainfall increases, and mean air temperature decreases. This conclusion is broadly consistent with global patterns across land use and land cover types.

Conant (2015) estimated C sequestration potential of grazing lands in SSA using a broad scale model-based approach. He estimated a C sequestration potential in SSA for a variety grazing land and land management changes of 37.3 Tg CO_2. This estimate was extracted from a global study (Henderson et al., 2015) and is therefore based on a limited number of data points and management practices. In order to improve this estimate a modeling exercise is needed which considers management practices specific to SSA and this needs to be underpinned by more measurements taken during field studies.

8. Recommendations

The following general recommendations for future projects and other activities addressing C sequestration in grazing lands in SSA came out of the two meetings and the reports:

I. C sequestration for climate change mitigation should be treated as a co-benefit rather than the target of a project/activity. There may be instances in which there are large social costs to C sequestration and by making sequestration the primary goal, a situation could arise where the social or economic burdens of the project could be greater than the climate change mitigation benefits. The likelihood of this is increased by the facts that the costs and benefits of C sequestration are not associated with the same people and the ones who must bear the costs (or burdens) are normally the poorest (Milne et al., 2015). That is to say, if the plan to sequester C involves a reduction in stocking rate or grazing intensity that does not result in an overall increase in production, it may have significant costs to the local livestock operators, but the benefits of C sequestration accrue to the world as a whole.

II. Paying people to maintain C stocks by persisting with existing good practices is likely to be easier than introducing new practices to increase stocks. In addition, significant potential for peer-to-peer learning among herders exists by highlighting good practices and promoting cross-site visits and other learning opportunities for successful herder-led sequestration initiatives which also makes up- and out-scaling of good practices effective.

III. Projects should be developed with strong input from the communities living in the areas (bottom up) where the project is to occur so that they have a sense of ownership of the project and are then more likely to cooperate in its implementation.

IV. When resources are limited, the focus should be on areas where the co-benefits of C sequestration and livelihood improvement are highest and this may be in moderately rather than severely degraded areas. Interventions should consider net livelihoods of local populations as a key metric of success of programs that aim to improve rangeland health and C sequestration.

V. There is less evidence of the impact of rangeland management approaches in enhancing C sequestration in non-equilibrial (erratic and changing) systems. Therefore it is much more difficult to detect management responses. This does not mean that we should not intervene in non-equilibrial systems; well managed grazing lands have the potential to enhance the capture of rainfall and radiation to increase Net Primary Productivity (NPP) and subsequently opportunities to enhance people's lives and landscapes. Furthermore, the long-term costs of neglecting these systems may be higher in some cases due to the difficulty of restoration where biophysical thresholds have been crossed.

VI. In terms of where to focus investment, from a purely biophysical C sequestration point of view, investment should be in areas where mineralization rates are low (cold, moist) or input rates are high (warm, wet) (Lal et al. 2015). For any potential sequestration activity, a holistic analysis is needed, including consideration of risk of land use conversion in the future and the permanence of any C sequestered. In areas where C sequestration rates are likely to be lower (arid, semi-arid) but cover extensive land areas, projects should include C sequestration as part of a package of multiple benefits in which practices that sequester C in grasslands enhance productivity, improve livelihoods, increase biodiversity and benefit multiple ecosystem services.

Acknowledgments

Supported by USAID Contract No. AID-OAA-L-10-00001, with Sustainable Landscapes Climate Change funding from the USAID Bureau for Africa, Office of Sustainable Development, via the Livestock and Climate Change Innovation Laboratory of the USAID Bureau for Food Security. The contents of this report do not necessarily reflect the views of the USAID or the U.S. Government. See full report at: http://www.vivo.colostate.edu/lccrsp/reports/GrazingLandsLivestockClimateMitigation_Paper1_Final6Aug2015editedv4a.pdf.

References

Ardo, J., Olson, L., 2003. Assessment of soil organic carbon in semi-arid Sudan using GIS and the Century model. J. Arid Environ. 54, 633–651.

Aynekulu, E., Vagen, T.-G., Shephard, K., Winowiecki, L., 2011. A Protocol for Modeling, Measurement and Monitoring Soil Carbon Stocks in Agricultural Landscapes. Version 1.1. World Agroforestry Centre, Nairobi.

Batjes, N.H., 2004. Estimation of soil carbon gains upon improved management within croplands and grasslands of Africa. Environ. Dev. Sustain. 6, 133–143.

Batjes, N.H., 2015. Map-based estimates of present carbon stocks of grazing lands in Sub-Sahara Africa. In: Milne and Williams (Eds.), Grazing Lands, Livestock and Climate Resilient Mitigation in Sub-Saharan Africa: The State of the Science. Report for USAID, Contract No. AID-OAA-L-10-00001, August 2015.

Conant, R.T., Paustian, K., 2002. Potential soil carbon sequestration in overgrazed grassland ecosystems. Glob. Biogeochem. Cycles 16, 1143.

Conant, R.T., 2015. Model based estimates of potential carbon sequestration in grass/rangelands in Sub-Saharan Africa. In: Milne and Williams (Eds.), Grazing Lands, Livestock and Climate Resilient Mitigation in Sub-Saharan Africa: The State of the Science. Report for USAID, Contract No. AID-OAA-L-10-00001, August 2015.

Follett, R.F., Reed, D.A., 2010. Soil carbon sequestration in grazing lands: societal benefits and policy implications. Rangeland Ecol. Manage. 63 (1), 4–15.

Henderson, B.B., Gerber, P.J., Hilinski, T.E., Falcucci, A., Ojima, D.S., Salvatore, M., Conant, R.T., 2015. Greenhouse gas mitigation potential of the world's grazing lands: modeling soil carbon and nitrogen fluxes of mitigation practices. Agric. Ecosyst. Environ. 207, 91–100.

Hengl, T., Heuvelink, G.B.M., Kempen, B., Leenaars, J.G.B., Walsh, M.G., Shepherd, K.D., Sila, A., MacMillan, R.A., Mendes de Jesus, J., Tamene, L., Tondoh, J.E., 2015. Mapping soil properties of Africa at 250 m resolution: random forests significantly improve current predictions. PLoS One 10, e0125814.

IPCC, 2006. IPCC Guidelines for National Greenhouse Gas Inventories. In: Eggleston, H.S., Buendia, L., Miwa, K., Ngara, T., Tanabe, K. (Eds.), Prepared by the National Greenhouse Gas Inventories Programme, IGES, Japan.

Jenny, H., 1941. In: Factors of Soil Formation: A System of Quantified PedologyMcGraw-Hill, New York Reprinted in 1994 by Dover Publications, Mineaola, NY.

Kamoni, P.T., Gicheru, P.T., Wokabi, S.M., Easter, M., Milne, E., Coleman, K., Falloon, P., Paustian, K., 2007. Predicted soil organic carbon stocks and changes in Kenya between 1990 and 2030. Agric. Ecosyst. Environ. 122, 105–113.

Lal, R., 2015. Cover cropping and the "4 per thousand" proposal. J. Soil Water Conserv. 70 (6), 141A.

Lal, R., Negassa, W., Lorenz, K., 2015. Carbon sequestration in soil. Curr. Opin. Environ. Sustain. 15, 79–86.

Milne, E., Williams, S. (Eds.), 2015. Grazing Lands, Livestock and Climate Resilient Mitigation in Sub-Saharan Africa, State of the Science. Report for USAID Project Contract No. AIDOAAL1000001 Available at: ⟨http://www.vivo.colostate.edu/lccrsp/reports/GrazingLandsLivestockClimateMitigation_Paper1_Final6Aug2015editedv4a.pdf⟩. (Last accessed 1.2.16).

Milne, E., Banwart, S.A., Noellemeyer, E., Abson, D.J., Ballabio, C., Bampa, F., Bationo, A., Batjes, N.H., Bernoux, M., Bhattacharyya, T., Black, H., Buschiazzo, D. E., Cai, Z., Cerri, C.E., Cheng, K., Compagnone, C., Conant, R., Coutinho, H.L.C., de Brogniez, D., Balieiro, Fd.C., Duffy, C., Feller, C., Fidalgo, E.C.C., da Silva, C. F., Funk, R., Gaudig, G., Gicheru, P.T., Goldhaber, M., Gottschalk, P., Goulet, F., Goverse, T., Grathwohl, P., Joosten, H., Kamoni, P.T., Kihara, J., Krawczynski, R., La Scala Jr, N., Lemanceau, P., Li, L., Li, Z., Lugato, E., Maron, P.-A., Martius, C., Melillo, J., Montanarella, L., Nikolaidis, N., Nziguheba, G., Pan, G., Pascual, U., Paustian, K., Piñeiro, G., Powlson, D., Quiroga, A., Richter, D., Sigwalt, A., Six, J., Smith, J., Smith, P., Stocking, M., Tanneberger, F., Termansen, M., van Noordwijk, M., van Wesemael, B., Vargas, R., Victoria, R.L., Waswa, B., Werner, D., Wichmann, S., Wichtmann, W., Zhang, X., Zhao, Y., Zheng, J., Zheng, J., 2015. Soil carbon, multiple benefits. Environ. Dev. 13, 33–38.

Thornton, P.K., Kruska, R.L., Henninger, N., Kristjanson, P.M., Reid, R.S., Atieno, F., Odero, A.N., Ndegwa, T., 2002. Mapping Poverty and Livestock in the Developing World. ILRI, Nairobi, Kenya.

UNCCD, 2015. Land degradation neutrality: resilience at local, national and regional levels, United Nations Convention to Combat Desertification, Bonn (DE), 24 p. ⟨http://www.unccd.int/Lists/SiteDocumentLibrary/Publications/Land_Degrad_Neutrality_E_Web.pdf⟩ (Last accessed 14.1.16).