Grasslands

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Globally, grasslands are among the largest ecosystems and cover around 3.5 billion-hectare (ha) area, representing 26 percent of the world land area and 70 percent of the world agricultural area (FAO, 2008). These grassland soils contain about 20 percent of the world's soil organic carbon (SOC) stocks (Conant, Paustian and Elliot, 2001). There are different types of grasslands: natural grasslands, semi-natural grasslands, and agricultural grasslands. Grasslands that are self-seeded are often defined as natural or native grasslands. These grasslands are predominated by grasses, grass-like plants, forbs, or shrubs suitable for grazing or browsing. They are defined as rangelands when natural (native) or grazed, and defined as pastures when forage is managed by seeding, mowing (i.e. for hay, silage, renewable energy production), fertilization and irrigation. Agricultural grasslands can be permanent (>5-years old) or temporary (i.e. included within the crop rotation, grass/arable-ley). Permanent grassland is often (semi-) natural. Grasslands are known as "Steppes" in Asia;

“Prairies” in North America; “Pampas”, “Llanos” and “Cerrados” (composed of forests, savannah-type and grassland-type formations) in South America; “Savannahs” and “Velds” in Africa; and “Rangelands” in Australia. These ecosystems support a variety of species, including wildflowers, and mostly feed various animals including 25 species of large plant-eaters. Other than natural, there are many degrees of interferences such as fire, grazing, clearing of woody vegetation, over sowing and large herds of wild herbivores that affect grassland systems.

Grasslands (pasture, silage and hay) dominate major agricultural areas and contribute 20-30 percent to the SOC pool and, by sequestering atmospheric carbon dioxide (CO_2), can contribute to climate change mitigation (e.g. Reid *et al.*, 2004; Allard *et al.,* 2007). Livestock is grazed mostly on grassland worldwide (pasture and meadows) (Figure 13a) (Ritchie and Roser, 2013). In Europe (with exceptions such as UK and Ireland) and South Asia grasslands typically occupies less than 20 percent of total land area whereas global coverage for most continental regions is slightly less than 50 percent. In Central Asia and nearby countries, it can reach up to 70 percent. Livestock is bred across diverse climatic and environmental regions in all continents except Antarctica, e.g. from temperate regions to hilly and semi-arid terrain. The latter ranges from low-input pastoral production systems in arid and semiarid environments to highly intensive production in more mesic environments, integrating livestock-crop-forage systems (Figure 13b). Therefore, grassland is potentially less geographically constrained than arable farming. Pastoralism refers to mobile livestock herding in the dimension of either production or livelihood (Dong, 2016).

Pastoralism occurs where resources are limited and occupies about 18-23 percent of global land area. It supports around 200 million pastoral households (Neely *et al.*, 2009; Blench, 2001). Two essential forms of pastoralism exist all over the continents: (i) the nomadic (commonly practised in regions with little arable land) and (ii) transhumance (mostly seasonal movement of livestock between fixed summer and winter pastures) rearing of domesticated animals (Dong, 2016).

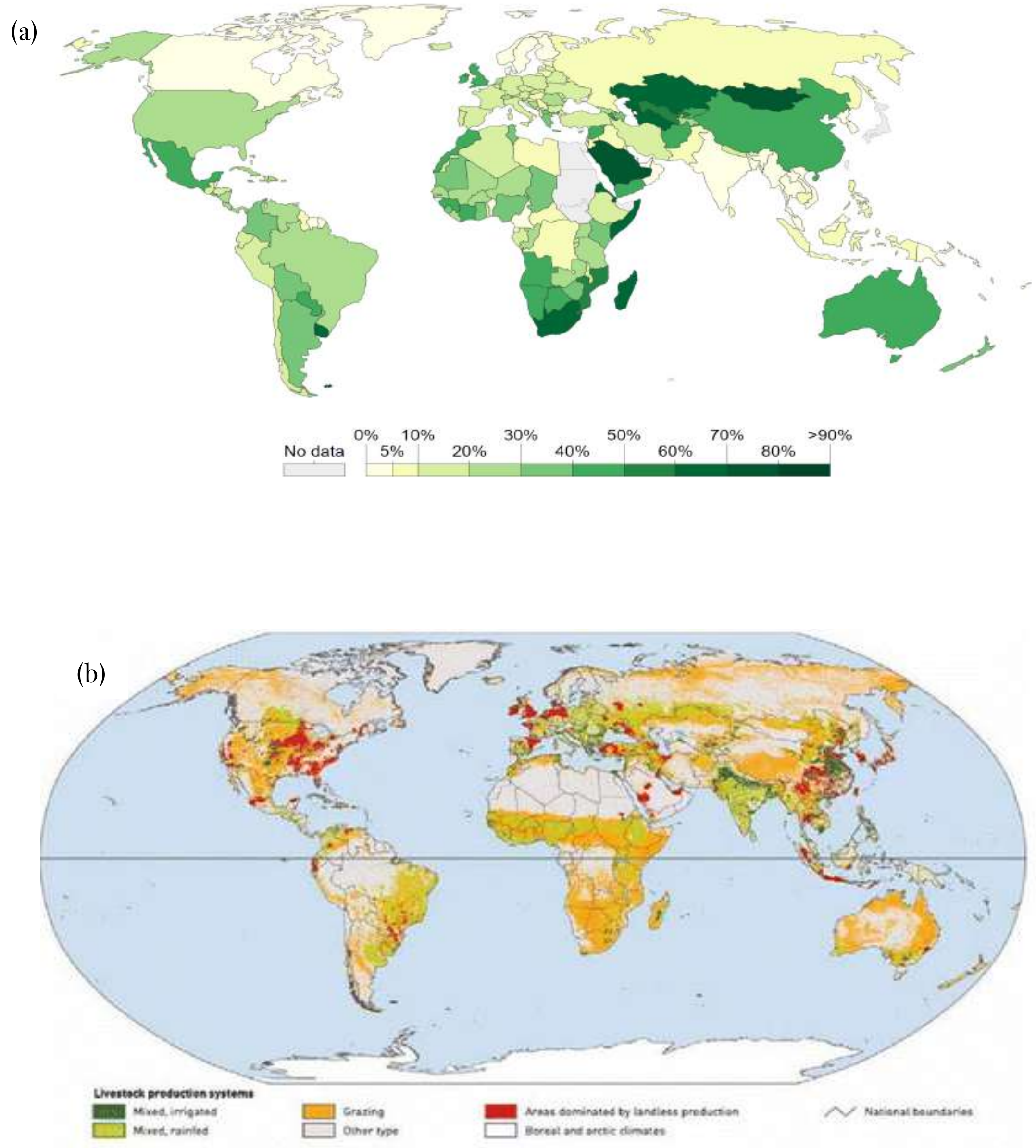

Figure 13. Global share of land area used for pastures, measured as the percentage of total land area, 1961-2014 (a), and livestock production systems (b). Source: FAO

Identifying optimum grassland management combining both profitable animal production and the delivery of ecosystem services like C sequestration is still a big challenge. The SOC densities/stocks are sensitive to management, re-seeding, drainage conditions, grass species and land use changes, inducing its losses or gains. Improved grazing management, inorganic and organic fertilization to pasture and silage, sowing legumes and improved grass species, irrigation, and conversion from cropland to grassland could lead to increased SOC, at rates ranging from 0.1 to more than 1 tC/ha/yr (Conant *et al.,* 2017; Khalil, Fornara and Osborne, 2020).

Grazing is a key factor in changing soil C pools in grassland ecosystems. In general, C sequestration is lower in mixed cutting/grazing systems than in pure grazing systems. Soil C storage depends on C input mainly through the belowground parts of vegetation and C release mediated by soil processes, which are influenced by soil physical, chemical, and biological properties (Batjes, 1999). Improved grazing management can improve conditions on many degraded soils (Nordborg and Röös, 2016), and unsustainable management practices bring soils to the limit of desertification, a situation that may deteriorate further with climate change (Lal, 2009).

Manure and other organic applications have significant potential for sequestering C in soils, but their management depends on local climatic and edaphic conditions and the characteristics of the materials amended (Khalil, Hossain and Schmidhalter, 2005; Khalil, Fornara and Osborne, 2020). Most soils are responsive to management changes to increase SOC density, such as: (i) set aside and restoration of degraded agricultural lands, (ii) manure/bio-solid applications (Ogle, Bredit and Paustian, 2005; Hutchinson, Campbell and Desjardins, 2007; Smith *et al.*, 2008), (iii) pasture improvement (Hutchinson, Campbell and Desjardins, 2007), (iv) adaptive grazing management systems (Bernues *et al.*, 2011; Teague ad Barnes, 2017), (v) selective inclusion of woody species into the pasture system (Howlett *et al.*, 2011), and (vi) conversion from cropland to pasture (e.g. Post and Kwon, 2000; McLauchlan *et al.*, 2006).

This section reviews management-induced C sequestration in grassland soils, their negative and positive impacts on ecosystem functions and their adaptability and needs of protection across socio-economic and cultural settings. The objectives of this section are to: (a) improve knowledge base and understanding of management practices and technologies to increase and maintain SOC, while reducing climate change risk and achieving overall productivity and environmental services; (b) suggest adopting region/biome-specific management practices to enhance/maintain SOC, protect ecosystems and environmental degradation without sacrificing food security; and (c) outline full realization of available economic, ecological, social and policy options to accept for storing additional SOC.

References

Allard, V., Soussana, J.-F., Falcimagne, R., Berbigier, P., Bonnefond, J.M., Ceschia, E., D'hour, P., Henault, C., Laville, P., Martin, C. & Pinares-Patino, C. 2007. The role of grazing management for the net biome productivity and greenhouse gas budget (CO_2, N_2O, and CH_4) of semi-natural grassland. *Agric. Ecosyst. Environ.,* 121: 47–58. https://doi.org/10.1016/j.agee.2006.12.004

Batjes, N.H. 1999. Management options for reducing CO_2 concentrations in the atmosphere by increasing carbon sequestration in the soil. *In Dutch National Research Programme on Global Air Pollution and Climate Change*. Report, 410: 200-031, Technical Paper, 30, ISRIC, Wageningen.

Bernués, A., Ruiz, R., Olaizola, A., Villalba, D. & Casasús, I. 2011. Sustainability of pasture-based livestock farming systems in the European Mediterranean context: Synergies and trade-offs. *Livestock Sci.,* 139: 44–57. https://doi.org/10.1016/j.livsci.2011.03.018

Blench, R. 2001. 'You Can't Go Home Again': Pastoralism in the New Millennium (p. 103). London: Overseas Development Institute. http://www.fao.org/3/y2647e/y2647e00.htm

Conant, R.T., Cerri, C.E.P., Osborne, B.B. & Paustian, K. 2017. Grassland management impacts on soil carbon stocks: a new synthesis. *Ecological Applications*, 27(2): 662-668. http://dx.doi.org/10.1002/eap.1473

Conant, R.T., Paustian, K. & Elliot, E.T. 2001. Grassland management and conversion into grassland: Effects on soil carbon. *Ecol. Appl.,* 11: 343-355. https://doi.org/10.1890/1051-0761(2001)011[0343:GMACIG]2.0.CO;2

Dong, S. 2016. Overview: Pastoralism in the World. *In* Dong, S., Kassam, K.A., Tourrand, J., Boone, R. (Eds.) *Building Resilience of Human-Natural Systems of Pastoralism in the Developing World*. Springer, Cham.

FAO. 2008. *Are grasslands under threat? Brief analysis of FAO statistical data on pasture and fodder crops*. 28p. http://www.fao.org/uploads/media/grass_stats_1.pdf

Howlett, D.S., Moreno, G., Losada, M.R.M., Nair, P.K.R. & Nair, V.D. 2011. Soil carbon storage as influenced by tree cover in the Dehesa cork oak silvopasture of central-western Spain. *Journal of Environmental Monitoring*, 13(7): 1897–1904. https://doi.org/10.1039/C1EM10059A

Hutchinson, J.J., Campbell, C.A. & Desjardins, R.L. 2007. Some perspectives on carbon sequestration in agriculture. *Agricultural and Forest Meteorology*, 142(2-4): 288–302. https://doi.org/10.1016/j.agrformet.2006.03.030

Jobbágy, E.G. & Jackson, R.B. 2000. The vertical distribution of soil organic carbon and its relation to climate and vegetation. *Ecological Applications*, 10: 323-638. https://doi.org/10.1890/1051-0761(2000)010[0423:TVDOSO]2.0.CO;2

Khalil, M.I., Hossain, M.B. & Schmidhalter, U. 2005. Carbon and nitrogen mineralization in different upland soils of subtropics treated with organic materials. *Soil Biol. Biochem.*, 37: 1507-1518. https://doi.org/10.1016/j.soilbio.2005.01.014

Khalil, M.I., Fornara, D. & Osborne, B. 2020. Simulation and validation of soil organic carbon density and its changes in a long-term permanent grassland of Ireland. *Geoderma*, 361: 114014. http://doi.org/10.1016/j.geoderma.2019.114014

Lal, R. 2009. Sequestering carbon in soils of arid ecosystems. *Land Degrad. Dev.*, 20: 441–444. https://doi.org/10.1002/ldr.934

McLauchlan, K.K., Hobbie, S.E. & Post, W.M. 2006. Conversion from agriculture to grassland builds soil organic matter on decadal timescales. *Ecological Applications*, 16: 143–153. https://doi.org/10.1890/04-1650

Neely, C., Bunning, S. & Wilkes, A. 2009. *Review of evidence on drylands pastoral systems and climate change: implications and opportunities for mitigation and adaptation*. FAO, Rome. (also available at: http://www.fao.org/uploads/media/LWdisc_paper8_temp.pdf)

Nordborg, M. & Röös, E. 2016. Holistic Management – a critical review of Allan Savory's grazing method. SLU/EPOK – Centre for Organic Food & Farming & Chalmers. 47pp.

Ogle, S.M., Bredit, F.J. & Paustian, K. 2005. Agricultural management impacts on soil organic carbon storage under moist and dry climatic conditions of temperate and tropical regions. *Biogeochem.,* 72: 87–121. https://doi.org/10.1007/s10533-004-0360-2

Post, W.M. & Kwon, K.C. 2000. Soil carbon sequestration and land-use change: process and potential. *Global Change Biology*, 6: 317–328. https://doi.org/10.1046/j.1365-2486.2000.00308.x

Reid, R.S., Thornton, P.K., McCrabb, G.J., Kruska, R.L., Atieno, F. & Jones, P.G. 2004. Is it possible to mitigate greenhouse gas emissions in pastoral ecosystems of the tropics? *Environment, Development and Sustainability*, 6(1): 91. https://doi.org/10.1023/B:ENVI.0000003631.43271.6b

Ritchie, H. & Roser, M. 2013. Crop Yields. In: *Our World in Data* [online]. [Cited 7 December 2020]. https://ourworldindata.org/crop-yields

Smith, P., Martino, D., Cai, Z., Gwary, D., Janzen, H., Kumar, P., McCarl, B., Ogle, S., O'Mara, F., Rice, C., Scholes, B., Sirotenko, O., Howden, M., McAllister, T., Pan, G., Romanenkov, V., Schneider, U., Towprayoon, S., Wattenbach, M. & Smith, J. 2008. Greenhouse gas mitigation in agriculture. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 363(1492): 789–813. https://doi.org/10.1098/rstb.2007.2184

Teague, R. & Barnes, M. 2017. Grazing management that regenerates ecosystem function and grazingland livelihoods. *African Journal of Range & Forage Science*, 34(2): 77–86. https://doi.org/10.2989/10220119.2017.1334706