Biochar for restoring degraded rangelands
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Abstract
Many of the world's rangelands are degraded. One of the major effects of the degradation processes is the depletion of the soil's organic carbon concentration, resulting in the decreased formation and stability of the soil structure, degraded food chains, and reduced fertility and productive capacity. Biochar, the by-product of pyrolysis technology for bio-energy production, has proven to have the capability to improve soil quality and increase vegetative production. At the same time, the inert nature of biochar enables long-term sequestration of carbon in soil. To date, the utilization of biochar has been examined almost exclusively in arable lands. It is hereby proposed that this practice could be relevant for the restoration of degraded rangelands. Biochar could be produced from several types of organic wastes. Wise implementation of this practice could considerably restore degraded rangelands and at the same time, store between 0.69 and 10.7 Pg (g x 10^{15}) carbon in their soil over the long-term.

1. Background
Rangelands constitute the most widespread use of land across the globe, and most are located in drylands. Degradation processes often result from the complex interactions of numerous factors, including climatic change, inappropriate land management, erroneous regulations, and political instability (Calvosa et al., 2010). On the whole, degradation processes of rangelands are attributed mainly to the over-exploitation of resources. The overall impact of degradation processes on the environment includes the destruction of habitats, loss of biodiversity, decreased vegetative cover, and soil erosion (Steinfeld et al., 2006).

The soil organic carbon (SOC) content is a major determinant of the soil's quality. Mismanagement of rangeland results in a decrease in the amount of organic residues that are returned to the soil, diminishing concentration of SOC and deteriorating the soil's productive capacity (Lal, 2009). Yet, given the complexity of rangeland ecosystems, overgrazing may contribute to an increase in the rangeland's carbon (C) stocks, for example, in cases of encroachment of woody vegetation. This process is attributed to the modifications in spatial redistribution of resources, which is caused by the grazing animals (Schlesinger et al., 1990).

2. Biochar
Biochar is a by-product of the pyrolysis technology for production of bio-energy from biomass under the exclusion of oxygen. Application of biochar increases soil fertility, augments its hydraulic conductivity, and boosts its microbial activity (Fowles, 2007). The relatively high concentration of C in biochar and its inert nature also make it an efficient means for long-term C sequestration (Lehmann et al., 2006). The production of biochar can be conducted through several means, for example, by using earth pits, earth mounds, or brick kilns that are designed for production of coal (see: FAO, 1987).

3. Challenges and opportunities
3.1. Low availability of potential feedstocks – In some cases, collecting manure from livestock pens and pyrolyzing it into biochar may be feasible. In cases of rangelands covered with invasive woody vegetation, they may be uprooted and pyrolyzed. However, the major challenge involved with this practice stems from the damage that is associated with heavy-machinery operations. Therefore, damage to the ground surface should be reversed as much as possible after uprooting in order to reclaim the surface soil and recover the original micro-topography. In other instances, locally grown agricultural wastes may also be considered as potential feedstocks.

3.2. Maintenance of spatial patchiness – The action of applying biochar to soil in rangelands may be destructive, increasing magnitude of erosional processes. A possible solution may be the application of biochar in certain spatial patterns, aimed at preventing the formation of spatial consecutiveness of low-stability and highly erodible surface soil. The spatial design may follow a range of natural patterns such as stripes, strands, or stiples (see: Ludwig et al., 1999).

3.3. Slow restoration rate – To accelerate the colonization of herbaceous vegetation, seeds may be planted in the charred patches. Also, biochar application can be coupled with the formation of small piles of branches of woody vegetation that increase surface roughness, act as seed traps, and improve micro-climatic conditions in the shaded patches. An additional practice is the construction of micro-catchments, aimed at increasing the accumulation of water in the charred patches. Also, native or introduced woody vegetation species may be transplanted to the micro-catchments, further increasing the rangeland's restoration capacity. The resulting increased roughness of the surface decreases the spatial consecutiveness and magnitude of erosional processes.

4. Carbon sequestration capacity
The application of biochar to soil in degraded rangelands around the world may considerably increase their C sequestration capacity. Considering that the world's degraded rangelands cover ~ 350 M ha (Steinfeld et al., 2006), and that biochar's C concentration is ~ 50% (Lehmann et al., 2006), and assuming a minimal application rate of 1 kg biochar m^{-2} (10 Mg ha^{-1}, in the case of croplands (Chan et al., 2007) on 25% of these lands' ground surface (similar to the cover of woody vegetation patches: Ludwig et al., 1999), the potential global C sequestration by this means is ~ 0.69 Pg.

Increasing the application rate would augment the C sequestration capacity accordingly. Since the application rate may be 10 times higher, namely 10 kg biochar m^{-2} (100 Mg ha^{-1}) (Chan et al., 2007), applying biochar at this rate may sequester ~ 6.9 Pg C in the soil of degraded rangelands across the globe. Assuming that C concentration in biochar can reach up to 78% (Gaskin et al., 2008), the C sequestration capacity through the application of biochar in the soil of worldwide degraded rangelands can reach up to ~ 1.1 Pg under a rate of 1 kg m^{-2} and up to 10.7 Pg under a rate of 10 kg m^{-2}.

5. Management and regulations
Application of biochar in the soil of degraded rangelands should be conducted in conjunction with appropriate regulations, aimed at recovering their productive capacity. To ensure the long-term sustainability these lands, the long-term management of stocking regimes is crucial.

Similarly to other land reclamation projects, these biochar projects should be funded by central authorities. The proposed mechanism is through payments for the improvement of ecosystem services. The most relevant ecosystem services, are C sequestration, soil erosion control, and preservation of off-site water source quality.

References