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ARTÍCULO DE REVISIÓN

Sociedad Colombiana de la Ciencia del Suelo

MANAGING SOILS OF COLOMBIA AND SOUTH AMERICA FOR ADDRESSING GLOBAL ISSUES AND ADVANCING SUSTAINABLE DEVELOPING GOALS

Manejo de suelos de Colombia y Sudamérica para abordar problemas globales y avanzar objetivos de desarrollo sostenible

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ABSTRACT

On behalf of the International Union of soil science, (IUSS) and on my personal behalf, I congratulate "Sociedad Colombiana De La Ciencia Del Suelo" (SCCS) on its 60th anniversary, and wish fellow soil scientists a bright and rewarding future ahead. Members of SCCS, in cooperation with those of IUSS and the Latin American Society of Soil Science, have an important role to play in addressing global issues and advancing the Sustainable Development Goals (SDGs) of the U.N. (The Agenda 2030). Soils of Colombia and those of South America, are diverse and have a high potential towards provisioning of numerous ecosystem services. Thus, sustainable management of soils is essential to alleviating poverty, eliminating hunger, enhancing racial/cultural/gender equity, increasing biodiversity, sequestering carbon for adapting and mitigating climate change, improving water quality and renewability and advancing SDGs. In addition to strengthening science of soils, the SCCS must also help translate knowledge into action by communicating with policymakers and cooperating with farmers. Furthermore, soil scientists must also be actively involved in education by including soil science in the curriculum of secondary schools, high schools, and at the university level. With these initiatives, the sky is the limit for future achievements of the SCCS in promoting human wellbeing while conserving and enhancing nature.

RESUMEN

En nombre de la Unión Internacional de Ciencias del Suelo, (IUSS) y en mi nombre personal, felicito a la Sociedad Colombiana de la Ciencia del Suelo (SCCS) en su 60 aniversario y deseo a mis colegas científicos del suelo un futuro brillante y gratificante. Los miembros de SCCS, en cooperación con los de IUSS y la Sociedad Latinoamericana de Ciencias del Suelo, tienen un papel importante que desempeñar al abordar los problemas mundiales y avanzar en los Objetivos de Desarrollo Sostenible (ODS) de la ONU (Agenda 2030). Los suelos de Colombia y los de Sudamérica son diversos y tienen un gran potencial para el aprovisionamiento de numerosos servicios ecosistémicos. Por lo tanto, el manejo sostenible de los suelos es esencial para aliviar la pobreza, eliminar el hambre, mejorar la equidad racial / cultural / de género, aumentar la biodiversidad, secuestrar carbono para adaptar y mitigar el cambio climático, mejorar la calidad del agua y la renovabilidad y avanzar en los ODS. Además de fortalecer la ciencia de los suelos, el SCCS también debe ayudar a convertir el conocimiento en acción mediante la comunicación con los responsables de la formulación de políticas y la cooperación con los agricultores. Además, los científicos del suelo también deben participar activamente en la educación al incluir la ciencia del suelo en el plan de estudios de las escuelas secundarias, secundarias y a nivel universitario. Con estas iniciativas, el cielo es el límite para los logros futuros del SCCS en la promoción del bienestar humano mientras se conserva y mejora la naturaleza.

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INTRODUCTION

Global issues of the 21st century, accentuated by the ramifications of anthropocene, include: (i) meeting food demands of the increasing and richer population by producing 3 billion tons of food grains and 500 million tons of meat by 2050 (FAO, 2009), (ii) adapting and mitigating climate change caused by anthropogenic emissions of 9.9 ± 0.5 Pg C/yr from fossil fuel combustion and 1.3 ± 0.5 Pg C/yr from land use conversion (Le Quéré et al., 2016), (iii) reducing loss of species at 1,000 to 10,000 times compared with the background rate of merely 1-5 species/yr (Dell'Amore, 2016), (iv) coping with rapid urbanization both globally (+1 billion) and in Latin America and the Caribbean (+127 million) between 2007 and 2025 driving deforestation and other resource extraction (USAID, 2010), (v) reducing poverty both urban and rural, which has increased from 28.2% in 2012 to 29.2% in 2015 (World Economics Forum, 2017), and (vi) mitigating the high impact of climate change on agricultural productivity in South America or SA (Vergara et al., 2014). Biodiversity in some sensitive eco-regions of SA is also affected by tourism, through informal trails created within the biodiversity hotspots (Barros et al., 2013). The answer to these and other issues lies in sustainable management of soil resources of SA in general and those of Colombia in particular because "soil matters" in a significant way. Whereas the annual carbon (C) emissions from fossil fuel combustion and cement production in SA contribute merely 2.5% (0.25 Pg C) of the total global emission, SA contributes > 30% (0.34 Pg C) of the global emissions through land use change (Sá et al., 2017). Furthermore, SA has a large potential terrestrial C sink capacity (~8.24 Pg C) between 2016 and 2050 (Sá et al., 2017), which must be harnessed in a quest to re-carbonize the biosphere.

SA has the world's second-largest remaining potential of future expansion of rain-fed agriculture (363 M ha), and of renewable water resources estimated at 13,500 km^3 (Alexandratos and Bruinsma, 2012). Indeed, sustainable management of soils of SA can significantly advance the Sustainable Development Goals (SDGs) of the U.N. or the Agenda 2030, especially with regards to ending poverty (Goal #1), eliminating hunger (Goal #2), improving water resources (Goal #6), promoting sustainable cities and communities (Goal #11), mitigating climate change (Goal #13), and enhancing biodiversity (Goal #15) (U.N. 2015). Therefore, the objective of this article is to congratulate the Colombian Society of Soil Science on its 60th anniversary, and also highlight the importance of sustainable management of soil resources of SA and of Colombia for addressing some global issues of the 21st century. The specific objectives are to outline some technological options of sustainable management of soils of SA to advance SDGs and address global issues.

Soil Carbon Sequestration

Soils of SA have a large potential to sequester atmospheric carbon dioxide (CO_2) and improve adaptation to and mitigation of the climate change. The data on C balance show that SA was a net source of C to the atmosphere during the 1980s (0.3-0.4 Pg C/yr)(Pg= petagram =1015g= 1billion metric ton=1 Gt) and close to neutral during 1990s (0.1 Pg C/yr.) (Gloor et al., 2012). However, with better land use and soil management, SA can be a net sink. With the terrestrial C sink capacity of 8.24 Pg C (Sá et al., 2017) terrestrial ecosystems of SA, have a potential draw down capacity of reducing atmospheric concentration of CO_2 by 4 ppm. However, the adverse effects of climate change on soils (Quafoku, 2015), especially on those of SA with a high SOC stock, cannot be ignored. Promoting adoption of conservation agriculture (CA), already practiced on 70 Mha of cropland in SA (out of the world total of 180 Mha or 39% of the global land area under CA) (Kassam et al., 2017), is an important strategy of restoring the SOC stock (Lal, 2015). The rate of SOC sequestration with CA system depends on numerous factors. (i.e., climate, soil type) but especially on the amount of input of biomass C. De Campos et al. (2011) observed a linear correlation between amount of C input (Mg/ha) [SOC stock (Mg/ha) = 59.20+ 4.07 (Input of Biomass C, Mg/ha), $R^2 = 0.98$]. The rate of SOC sequestration can also be enhanced by alleviation of soil acidity. Acid soils cover 80% of the agricultural area in Colombia, of which 17 M ha is in the Llanos Orientales region.

Effectiveness of CA to sequester atmospheric CO_2 can be enhanced when used in conjunction with

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deep rooted grasses and other forages. In Colombia, Fisher et al. (1994) reported that growing deep-rooted pastures could account for the sequestration of 100-507 Tg C/yr (Tg=teragram=10^{12}g= 1 million metric ton= 1Mt) throughout SA and offset anthropogenic emissions. Improved management of tropical grasslands and savannas may have a terrestrial C sink capacity of up to 0.5 Pg C/yr (Scurlock and Hall, 1998). The rate of SOC sequestration can be 0.1-0.2 Mg C/ha in dry land farming system (Farage et al., 2007) and much higher in soils of the humid tropics (Sá et al., 2017). Root dynamics of introduced pastures is an important factor affecting the SOC sequestration (Trujillo et al., 2006). The mechanisms of SOC sequestration (e.g., physical aggregate protection, SOC-clay interaction, dissolved organic carbon transport, bioturbation for deep translocation of SOC) must be identified and enhanced through adoption of site-specific soil management practices (Jimenez and Lal, 2006).

Climate Change and Soil Degradation in South America

The projected climate change in SA will aggravate variations in temperature and precipitation over SA between circa 1860 and 2100 (Teleginski-Ferraz et al., 2006), with large changes in daily temperature extremes (Vincent et al., 2005) especially in the Andean region (Viddalba et al., 2003). Climate change, with increase in frequency and intensity of extreme events, can exacerbate the extent and severity of soil degradation in SA. Climate change affects soil degradation by altering the hydro-thermal regimes and increasing the risks of soil and water degradation so much so that by mid-century there may be a gradual shift in replacement of forest cover by savannah in eastern Amazonia (FAO, 2017). Thus, risks of an accelerated soil erosion can be increased by the climate change. More than 68% of the soils in SA are prone to accelerated erosion, and as much as 100 M ha of land has been degraded (Milesi and Jarroud, 2016). About 45% of croplands in SA are affected by degradation (Santibáñez and Santibáñez, 2007), and that Colombia has lost 0.9 M ha of tropical rainforest, and part of the loss was due to the adverse effects of accelerated erosion (Anonymous, 2010). The projected climate change can strongly impact soil properties, and reduce the SOC stock (Chakravorty, 2017). With a broad range of biomes (tropical rainforest, savannas, highlands) covering a total land area of 1753 M ha, the effects of climate on SOC stock may vary among eco-regions. Rangelands cover 30% of the total land area in SA (Yahdjian and Sala, 2008). Hugo (2006) outlined some generic trends of land degradation in SA by different process (Table 1). In addition to erosion, soil salinization is also a problem in many countries of SA, especially of the irrigated lands in arid and semi-arid regions (Table 2). Based on the UNEP's project on "Global Assessment of Soil Degradation" (GLASOD), Oldeman (1994) estimated the area affected by soil degradation in SA at 243 M ha (Table 3). Of this, land area (M ha) affected by different causes of degradation was 100 by deforestation, 12 by overexploitation, 68 by overgrazing, and 64 by

Table 1. Estimates of the risks of soil degradation in some countries of South America (The data in this Table are extracted from Hugo, 2006).

Country	Soil Degradation Process	Land Area (10^6 ha)
Chile	Soil erosion	172.4 (out of total area of 278) or 62% of the territory
Bolivia	Soil erosion	42.8
Argentina	Water and wind erosion	60, new land affected 0.2-0.65 /yr.
Brazil	Soil erosion, deforestation, physical and chemical degradation	-
Colombia	Soil degradation	54.2
Ecuador	Erosion	3.1
Peru	Erosion	60.0
Uruguay	Land degradation	5.2
Venezuela	Salinization	-

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Table 2. Estimates of land area affected by soil salinization in South America (Recalculated from FAO and ITPS, 2015).

Country	Land Area Affected by Soil Salinization (10^6ha)
Argentina	85.0 of which 0.6 are irrigated
Brazil	0.125-0.175 of irrigated lands in the northeastern region
Colombia	8.66
Cuba	0.1
Ecuador	Irrigated soils of the highlands
Mexico	6.0
Peru	0.3 in coastal areas
Venezuela	-

Table 3. Estimates of soil degradation in South America (Adopted from Oldeman, 1994).

Process	Land Area Affected (10^6ha)
Erosion by water	123
Erosion by wind	42
Chemical degradation	70
Physical degradation	8
Total	243

agricultural activities. The problem of soil degradation is triggered by land cover change, deforestation, and inappropriate land use and soil mismanagement.

Deforestation and Land cover Change

Latin America and the Caribbean (LAC) region, of which SA is the major component, has the world's largest reserves of potentially arable land. As much as 47% of the land is still covered by forest, but the rate of land use conversion is high. Thus, land use change occurs more rapidly in LAC region than anywhere else in the world, and it has a strong impact on the global carbon cycle(GCC). Between 1961 and 2011, the agricultural land area in the LAC region increased from 561 M ha to 741 M ha, with the largest expansion in SA from 441 to 607 M ha (FAO, 2017). The annual rate of deforestation in SA increased from 3.62 to 4.44 M ha between 1990-2000 and 2000-2005, along with the related increase in the terrestrial C loss of 0.41 to 0.50 Tg C/yr. (Table 4).

Loss of the vegetation cover upon conversion to agriculture exacerbates the risks of soil degradation. Deforestation strongly impacts the above and below-ground C stocks, and conversion from natural to managed ecosystems is still a major issue in SA. Deforestation also results in the loss of terrestrial C and degradation of soil quality. The LAC region accounts for 14% of the global degradation. Four LAC countries have 40% of their national territory degraded, and the level of degradation is also affected by the current agricultural practices especially the susceptibility to wind and water erosion, soil compaction, SOC depletion, nutrient losses and acidification (Wingeyer et al., 2015).

In Colombia, however, forest recovery trends have been observed between 2001 and 2010

Table 4. Estimates of deforested area and the loss of C from the ecosystems in South America (Adapted from De Sy et al., 2015).

Land Use	1990-2000		2000-2005	
	Area (10^6 ha)	C Loss (Tg C/yr.)	Area (10^6 ha)	C Loss (Tg C/yr.)
Agriculture	3.19	351	3.97	445
Others	0.43	54	0.49	55
Total	3.62	365	4.46	500

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(Sanchez-Cuervo et al., 2012). There was a net gain of 1.70 M ha of woody vegetation at the national scale between 2001 and 2010. The majority of this gain occurred in the Moist Forest Biome (Sanchez-Cuervo et al., 2012). The recovery of forest in Colombia (Sanchez-Cuervo et al., 2012) is a positive trend with beneficial impacts on C sequestration in above and below ground components. However, there are a few data on the impact of biomass recovery of the once forested land on C sequestration rate in biomass and soil which have not been widely studied. Poorter et al. (2016) observed that the rate of above ground biomass recovery in the secondary forest over 20 years was 122 Mg/ha at the average rate of 3.05 Mg C/ha.yr. or 11 times the rate of biomass C sequestration in the old-growth forest. The data of a study on 45 sites and 1500 forest plots showed that it took 66 years to recover 90% of the biomass in old-growth forests (Poorter et al., 2016). The range of rate of biomass C recovery in the LAC region ranged from 22 to 225 Mg/ha, by a factor of 11.3. Management of secondary forests in the LAC region can have strong impacts on mitigation of climate change (Locatelli et al., 2011). A study conducted by Chezdon et al. (2016) indicated a total above-ground C stock of 8.48 Pg in 240 M ha of secondary forest. Chezdon et al. (2016) concluded that permitting natural regeneration on 40% of lowland pastures can sequester 2.0 Pg C over 40 years, which is a low-cost strategy to mitigate the climate change. With C price of $20/Mg, Benitez et al. (2006) estimated that reforestation of < 4% of the area suitable for afforestation and reforestation would bring economic benefits of $2.3 billion over 20-year period. The Noel Kempft Climate Action Project in Bolivia is an example of carbon-based conservation strategy (Cohen, 2002). The rate of SOC recovery in soil also varies widely, and is strongly governed by the input of biomass-C into the cropland. With numerous competing uses, the amount of residues retained varies widely (Turmel et al., 2015).

Restoring Soils of South America for Advancing Sustainable Development Goals of the U.N.

Several SDGs of the Agenda 2030 (SDG #1,2,6, 13 and 15) can be strategically advanced by re-carbonization of the soil and the forest biomass in SA. Conversion of natural to agroecosystems has depleted the ecosystem C stock with adverse impacts on soil functionality. Sloping croplands of SA are also prone to accelerated erosion. Deforestation, cultivation-induced erosion, and mineralization of soil organic matter (SOM) under conditions of high temperatures have severely degraded soil quality/health. FAO and ITPS (2015) reported that soils of the following eco-regions in the LAC are under threat: tropical and sub-tropical moist forests; tropical and sub-tropical grasslands, savannahs and shrub lands ; deserts and xeric shrub lands dry tropical and sub-tropical broadleaf forest; montane grasslands and shrub lands, tropical and sub-tropical coniferous forests; and flooded grasslands and savannahs; and mangroves. Major soil threats in these regions include: erosion by water and wind; SOC depletion; salinization and sodication; nutrient imbalance, loss of biodiversity, compaction; waterlogging; soil acidification; sealing etc.

Therefore, restoration of degraded soils and ecosystems is essential to sustain production, adapt and mitigate climate change, enhance biodiversity and improve quality and renewability of water resources. There exists a large potential of C sequestration in soils (Lal et al., 2006), agroecosystems (Sá et al., 2017) and in the secondary growth forests (Poorter et al., 2016).

While there is a potential to expand the land area under agro-ecosystems, such a strategy has numerous trade-offs and must be critically considered. Indeed, some of the degraded lands under pastures, especially these in the Amazonian region, should be afforested or set aside for nature conservancy. Therefore, policy intervention is critical to the re-carbonization of depleted and degraded soils of agroecosystems in SA.

Eco-Region Specific Management of Colombian Soils

García-Ocampo (2012) outlined appropriate cropping/farming systems for predominant soils in diverse eco regions of Colombia, and outlined opportunities for increased agricultural production by suggesting alternative and soil-specific cropping practices. García-Ocampo opined that sugarcane planted on Alfisols, Vertisols and Mollisols can pro-

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duce 14 Mg/ha. month with a high sugar production, tropical fruit production can be maintained at >40 Mg/ha.yr. in soils of the Andean or the Caribbean region, and 33-35 Mg/ha of oil palm can be produced in soils of the humid regions. Adoption of complex farming systems can also improve physical, chemical, and biological soil properties while sustaining high production. A high productivity can be maintained by improved management that enhances soil quality. Because acid soils cover 80% of the agricultural area in Colombia, of which 17 M ha occur in Llanos Orientales, a judicious management of soil acidity is critical to sustaining agronomic productivity.

CONCLUSIONS

South America has a vast amount of diverse soils, forests and water resources. Even with a low population density, the region has and is undergoing a rapid land use conversion from natural to managed (agricultural, plantations, urban) ecosystems, with strong attendant impacts on the GCC, decline in soil quality, change in water and energy budgets, and reduction in biodiversity. Whereas the use of modern systems of agriculture in Brazil, Colombia, Argentina, Chile, Paraguay, etc. have made strong and positive impacts on global food and nutritional security, there are also strong impacts on soil quality and water resources. Soil resources are adversely affected by a range of degradation processes including erosion by water and wind, salinization and sodication, SOC depletion, nutrient imbalance, acidification etc.

Rather than expanding the land area under agroecosystems, a viable option is to restore degraded soils, convert some of the degraded pasture lands back to secondary forest growth, and undertake afforestation of sloping and highly erodible lands. These strategies would lead to re-carbonization of the biosphere, restoration of in degraded lands, increase biodiversity and advance of the Agenda 2030.

Conversion to a restorative land use and adoption of proven and validated best management practices under site-specific conditions can enhance production while also restoring soil quality/health, adapting and mitigating climate change, improving biodiversity and enhancing quality and renewability of water resources.

Restoration and sustainable management of soil, agroecosystems and vegetation in diverse biomes of SA has a strong potential to advance SDGs or the Agenda 2030 of the U.N. The SCCS is to be complemented for a phenomenal progress over the past 60 years, and IUSS wishes it even a bigger success in the future.

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