Sustainability **2015**, *7*, 12490-12501; doi:10.3390/su70912490

OPEN ACCESS

sustainability

ISSN 2071-1050

www.mdpi.com/journal/sustainability

Editorial

Soil Degradation: Will Humankind Ever Learn?

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Academic Editor: Marc A. Rosen

Received: 10 July 2015 / Accepted: 3 September 2015 / Published: 11 September 2015

Abstract: Soil degradation is a global problem caused by many factors including excessive tillage, inappropriate crop rotations, excessive grazing or crop residue removal, deforestation, mining, construction and urban sprawl. To meet the needs of an expanding global population, it is essential for humankind to recognize and understand that improving soil health by adopting sustainable agricultural and land management practices is the best solution for mitigating and reversing current soil degradation trends. This research editorial is intended to provide an overview for this Special Issue of *Sustainability* that examines the global problem of soil degradation through reviews and recent research studies addressing soil health in Africa, Australia, China, Europe, India, North and South America, and Russia. Two common factors—soil erosion and depletion of soil organic matter (SOM)—emerge as consistent indicators of how "the thin layer covering the planet that stands between us and starvation" is being degraded. Soil degradation is not a new problem but failing to acknowledge, mitigate, and remediate the multiple factors leading to it is no longer a viable option for humankind. We optimistically conclude that the most promising strategies to mitigate soil degradation are to select appropriate land uses and improve soil management practices so that SOM is increased, soil biology is enhanced, and all forms of erosion are reduced. Collectively, these actions will enable humankind to "take care of the soil so it can take care of us".

Keywords: soil health; soil quality; sustainable intensification; soil biology; erosion; soil organic matter; carbon sequestration

1. Introduction

This research editorial is intended to establish the context and provide a broad overview for the Special Issue of *Sustainability* entitled "Enhancing Soil Health to Mitigate Soil Degradation" that was initiated in 2014 to document both the magnitude and global prevalence of soil degradation. Our goals for the Special Issue were to: (1) help illustrate various factors contributing to the problem of soil degradation; (2) identify past and current impacts of soil degradation in countries around the world; and (3) suggest soil health strategies that could be used to protect our fragile soil resources.

As our global population marches steadily toward projections of 9.5 billion in 2050, natural and human induced soil degradation, if not mitigated, will undoubtedly increase the potential for negative impacts such as disease and malnutrition [1]. Currently, those problems are most severe in mountainous, tropical latitude areas of Central and South America where natural or environmentally induced soil degradation (e.g., landslides) is prevalent, and in Africa, which unlike Asia, has not been able to capitalize on benefits associated with the traditional "green revolution" even though the rate of adoption of improved crop varieties was equivalent to the rate in other developing regions around the world. In Africa, depletion of soil nutrients and poor water management are the major limiting factors, not the lack of improved crop varieties. Several recent studies confirm that no matter how good genetic improvement is, crops cannot grow well without sufficient nitrogen (N), phosphorus (P), and other essential plant nutrients. Sanchez and Swaminathan [1] also concluded that the root cause for many of Africa's malnutrition and subsequent social problems stems from a catastrophic "crisis in soil health." For years, Africa's small-scale farmers have removed large quantities of nutrients from their soils without returning them through either manure or fertilizer sources. The removal of almost all crop residues has also resulted in decreased SOM, impaired soil biological activities, weakening of soil structure, and impaired water dynamics—*i.e.*, infiltration, retention and release for plant growth. Within the Special Issue, Tully *et al.* [2] focus on soil degradation in sub-Saharan Africa (SSA), which we fully recognize is just one area within a vast continent that is struggling to mitigate the problem. Similarly, as stated above, but not adequately addressed, there are several in countries in Central America, especially the Andean ones, that are also struggling against soil degradation. In many of them, the combined impacts of agricultural activity, climate change, and extreme environmental events have had severe consequences that illustrate the global prevalence of severe soil degradation problems.

Unfortunately, soil degradation is not a new problem for humankind. Greek and Roman philosophers were well aware of the importance of soil health to agricultural prosperity and demonstrated this understanding in their treatises on farm management more than 2500 years ago. An example from Hillel [3] is an account whereby Plato has Critias proclaim:

> "What now remains of the formerly rich land is like the skeleton of a sick man, with all the fat and soft earth having wasted away and only the bare framework remaining. Formerly, many of the mountains were arable. The plains that were full of rich soil are now marshes.

> Hills that were once covered with forests and produced abundant pasture now produce only food for bees. Once the land was enriched by yearly rains, which were not lost as they are now, by flowing from the bare land into the sea. The soil was deep, it absorbed and kept the water in the loamy soil, and the water that soaked into the hills fed springs and running streams everywhere. Now the abandoned shrines at spots where formerly there were springs attest that our description of the land is true."

Hillel [3] provides many other references from current and historical times that address concerns related to the health of soil and land resources. Similar concerns regarding humanity's history of poor soil resource management, apparent lack of concern for soil health, and consequences of our negligence can be found in writings of Lowdermilk [4], Montgomery [5], and Larson, who often stated that soil is "the thin layer covering the planet that stands between us and starvation" [6].

2. Global Soil Degradation Perspectives

Several national research councils and advisory boards have published strategic papers related to soil resources. All reports agree that the state of our soils is deteriorating and that there is an urgent need to improve soil health (e.g., the National Research Council (NRC), the Royal Society of Chemistry (London) (RSC), the German Advisory Council on Global Change (WBGU). The most significant threats to soils around the world are:

(1) Erosion (wind and water)
(2) Loss of SOM (also referred to as carbon, soil carbon, or soil organic matter)
(3) Nutrient imbalance
(4) Salinization
(5) Surface sealing
(6) Loss of soil biodiversity
(7) Contamination
(8) Acidification
(9) Compaction
(10) Waterlogging

The degree of severity, geographic extent and interaction between these threats are diverse and complex. Degradation of soil results in the loss of critical functions and ecosystem services. These functions and services include production of food, feed, fuel, and fiber ensuring sufficient supplies of clean water, providing a platform for the built environment, acting as a buffer against extreme climatic events, supporting biodiversity, and providing the largest terrestrial store of carbon and nutrients [7].

Degrading soils cover approximately 24% of the global land area (35 million km^2 or 3500 million ha) [8]. Furthermore, the new global Land Cover Share-database [9] shows that croplands cover 13% of the global land surface and that grasslands, which are often used for grazing, cover another 13%. While agriculture is not the sole cause of soil degradation it is a dominant factor. Around 1000 AD cropland and pasture accounted for 1% to 2% of the ice free land area [10]. As the human population expanded, 2% to 4% of the land was in agriculture by 1700 (Figure 1). By 1900, expansion occurred into North America and by 2000, intensive agricultural practices expanded further with significant population increases in South America, Africa and Asia that have resulted in current day totals (Figure 2).

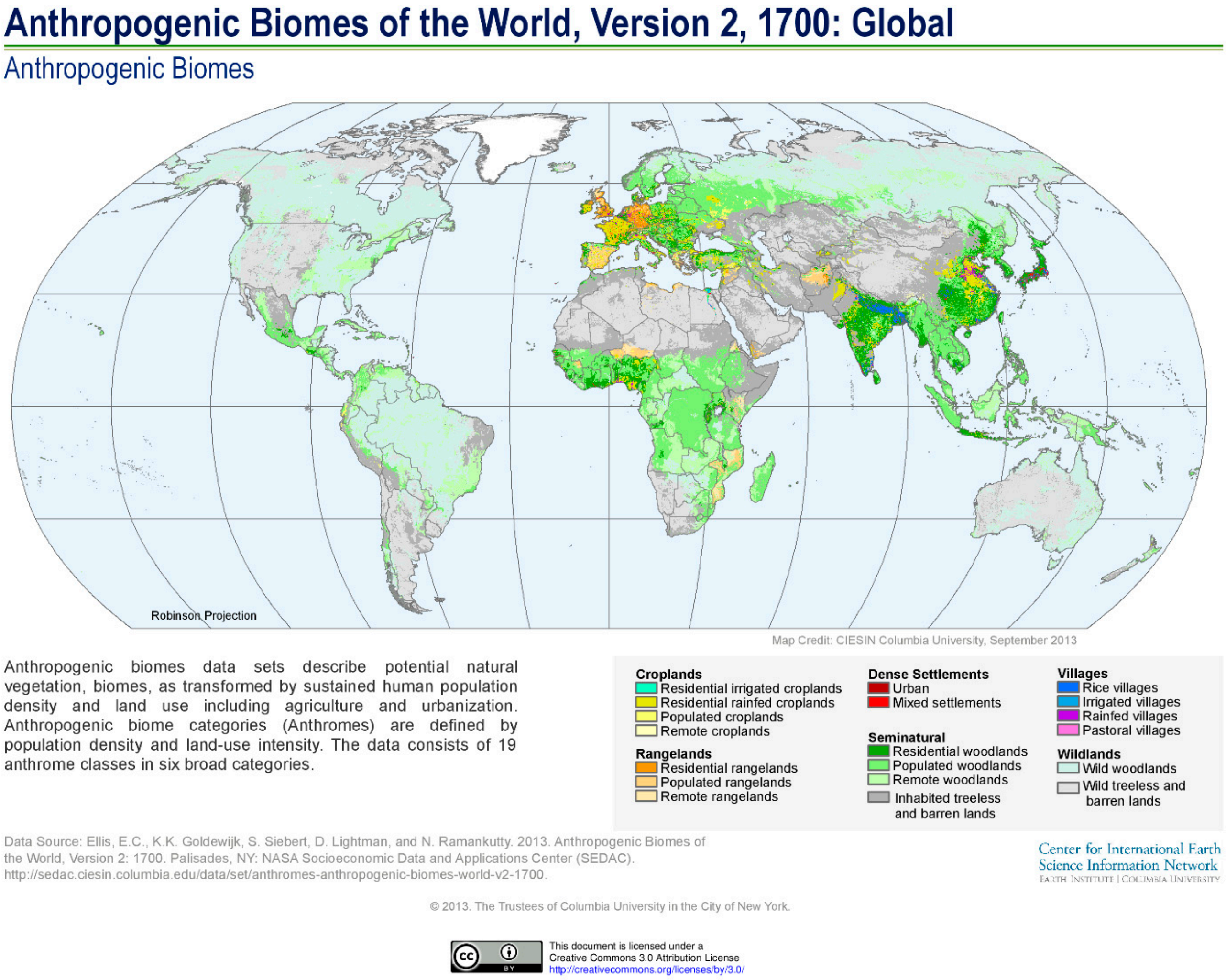

Figure 1. Global land use projected for 1700 [11].

One of the key drivers of soil degradation is land use change (LUC). An example of how LUC is affecting soil structure in Brazil is shown in Figure 3. Due to increasing global demand for bioenergy feedstock, native biomes such as the Cerado are being converted first to pasture and then to sugarcane (*Saccharum officinarum*). Soil health assessment techniques such as Visual Evaluation of Soil Structure (VESS) [12,13] are being used to document how LUC is affecting soil physical quality so that better soil and crop management practices can be implemented. Specifically, those pictures (Figure 3) show a relatively well-aggregated soil under native vegetation. Transition to pasture maintains an organic-matter enriched surface, but begins to show signs of compaction due to hoof traffic often associated with over-grazing. Finally, due to tillage and very heavy equipment associated with sugarcane production, soil structure is further degraded until productivity diminishes [14] or the site is restored through deep and aggressive tillage, but that in turn leads to accelerated decomposition of SOM.

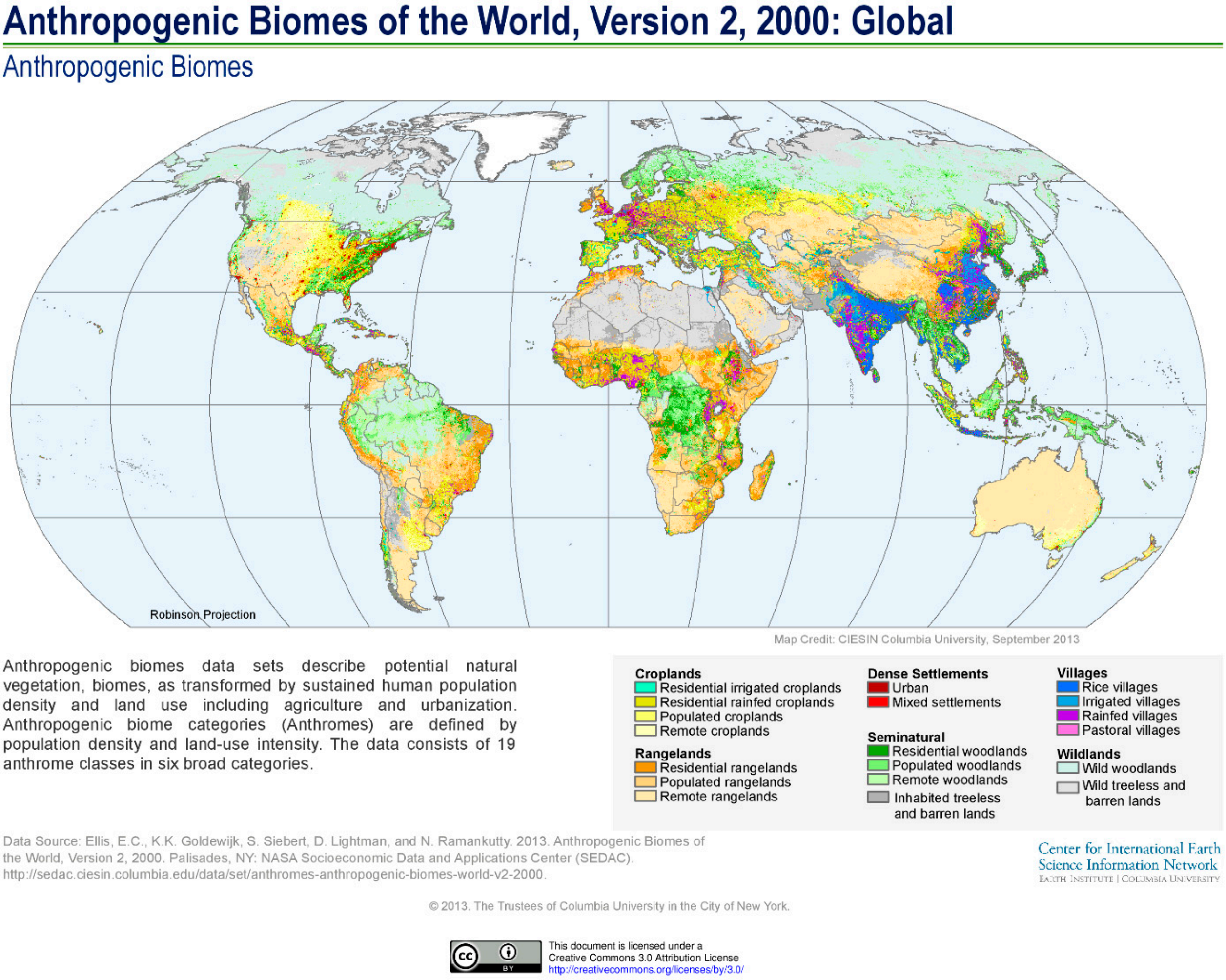

Figure 2. Global land use projected for 2000 [15].

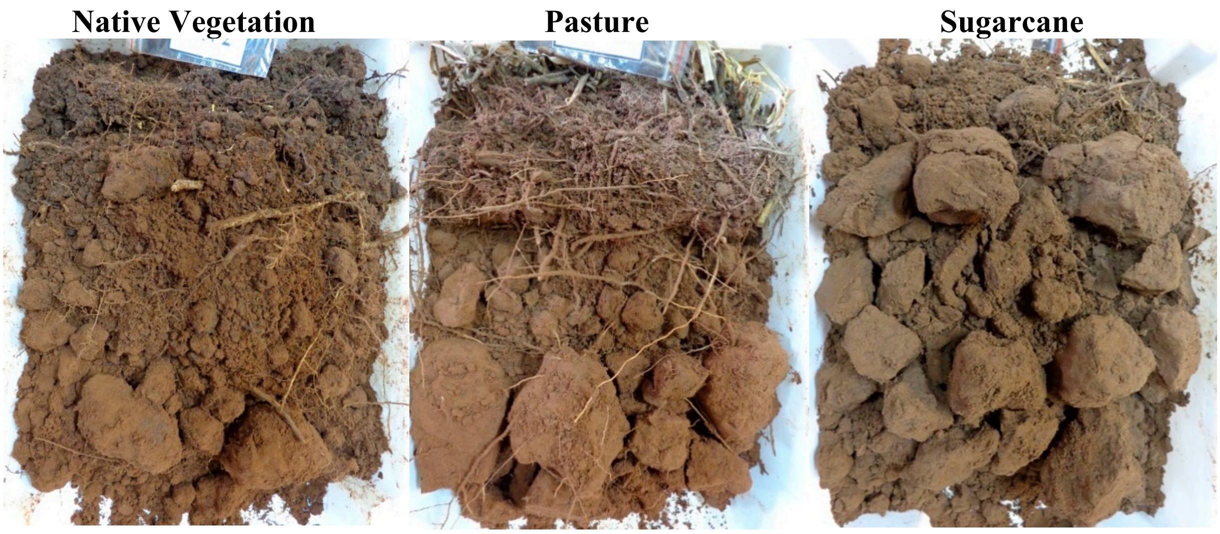

Figure 3. Land use change effects on the surface soil structure of an Oxisol in Brazil [14]. At U.S Department of Agriculture (USDA), National Laboratory for Agriculture and the Environment, Ames—IA, USA.

Soil change is a direct result of both population and economic growth. The world's population surpassed 7.3 billion in 2015 and is projected by the United Nations to reach 8.4 billion by 2030 and 9.6 billion by 2050. Estimates of global food demand, based on population growth and dietary shifts associated with economic growth, indicate that production will need to increase by 40% to 70% by 2050 [16]. Amazingly, from the period between 1961 and 2000 food production increased by 146% while the amount of land in agriculture production increased by only 8%. This was achieved through increased inputs of nutrients and water. However this intensification puts pressure on the soil resources and raises the question of whether additional food needs can be met without further degradation? Traditionally, there has been no consistent monitoring of either the extent or type of soil degradation, but FAO and the Global Soil Partnership [10] are expected to release a comprehensive State of the World Soil Resources Report in 2015. It is expected that this report will be the first of a series to document soil change.

Another indication that public awareness of the importance of soil resources is finally increasing is that 2015 has been proclaimed as the International Year of Soils by the United Nations. As a result, many efforts are being undertaken to increase public awareness of the importance of soil [17,18]. We suggest the papers contained in the Special Issue of *Sustainability* entitled "Enhancing Soil Health to Mitigate Soil Degradation" will contribute significantly to those efforts by highlighting the global need for more awareness and understanding of how complex soils are and how valuable they are to humankind.

3. Geographic Consistency in Soil Degradation

"Enhancing Soil Health to Mitigate Soil Degradation" includes in-depth reviews and research results from Africa, Australia, China, Europe, India, North and South America, and Russia that provide a very clear, strong and consistent message that soil erosion and depletion of soil organic matter are two key indicators of and therefore intervention points for reversing soil degradation.

Key points identified by the various authors are briefly summarized below to entice potential readers explore the problem of soil degradation and potential strategies for its remediation more fully in the regions that are most important to them. For example, many people consider the U.S. Dust Bowl to have been the first major event associated with soil degradation in North America [19], but in reality, the catastrophic wind erosion associated with that event was preceded by soil degradation due to water erosion in the southern U.S. and nutrient depletion in many New England areas. One of the most significant effects of the Dust Bowl, however, was that it provided the impetus to improve agricultural management of soils being degraded by both wind and water erosion. Currently, North American soils experience soil degradation due to compaction, salinization, acidification, and contamination by anthropogenic compounds, but wind- and water-induced soil erosion that results in deteriorated physical properties, nutrient losses, and reshaped, potentially unworkable, field surface conditions remains the predominant driver. A close second, however, is the loss of soil organic matter which decreases aggregate stability, weakens soil structure, and negatively impacts soil water availability to crops. The magnitude of SOM loss is documented by the fact that in North America soil organic matter concentrations are only about 50% of the level they were when land was converted from forests or prairies to farmland. In Bolivia, Paraguay, Uruguay, Argentina and southern Brazil [20], unprecedented adoption of no-tillage, as well as improved soil fertility and plant genetics have significantly increased yields and altered the role of these countries in helping meet an increasing global food and feed demand. However, various land use changes such as converting pasture to continuous soybean [*Glycine max* (L.) Merr.] or sugarcane have contributed to various levels of soil degradation through wind and water erosion. In Western Europe [21], the extent and causes of chemical, physical, and biological soil degradation and soil loss vary greatly, but agriculture and forestry are the main causes for physical degradation, erosion, and loss of SOM. In Eastern Europe [22], a diverse topography along with deforestation, changing climatic conditions, long-term human settlement, overuse of agricultural lands without sustainable planning, cultural difficulties in accepting conservative land management practices and wrong political decisions have all increased the vulnerability of many soils to degradation and resulted in a serious decline in their functional capacity. Once again, the predominant causes of soil degradation were water and wind erosion, organic matter depletion, salinity, acidification, crusting and sealing, and compaction.

Soil degradation in India [23] is estimated to be affecting 147 Mha which is extremely serious considering that country supports 18% of the world's human population and 15% of the animal population on just 2.4% of the global land area. The causes for this degradation are both natural and human induced. Natural causes include earthquakes, tsunamis, droughts, avalanches, landslides, volcanic eruptions, floods, tornadoes, and wildfires; while human-induced soil degradation results from land clearing and deforestation, inappropriate agricultural practices, improper management of industrial effluents and wastes, over-grazing, careless management of forests, surface mining, urban sprawl, and commercial/industrial development. Inappropriate agricultural practices include excessive tillage, use of heavy machinery, excessive and unbalanced use of inorganic fertilizers, poor irrigation and water management techniques, pesticide overuse, inadequate crop residue and/or organic carbon inputs, and poor crop cycle planning. Contributions from both China [24] and Russia [25] focus primarily on wind erosion. To decrease soil loss and enhance local ecosystems, the Chinese government has been encouraging residents to reduce wind-induced soil degradation through a series of national policies and several ecological projects. These measures include conservation tillage, windbreak networks, checkerboard barriers, afforestation, and grassland enclosures. As a result, the aeolian degradation of land in many regions of arid and semiarid northern China are being controlled. In Russia, extensive cultivation of Chernozems that were some of the most naturally fertile soils in the world, with thick A horizons, lost a significant amount of the original organic matter stocks and had become much less productive by the second half of the 19th century. Restoration programs focused on planting windbreaks were implemented to rehabilitate and remediate the degraded soils. These practices protected cropland from wind and water erosion, improved the microclimate for crop growth, and provided new refugia for wild animal and plant habitats. During the last several decades, these windbreaks have begun to be viewed as ecosystems with great potential for atmospheric carbon sequestration, which plays a positive role in climate change mitigation while also improving soil quality by increasing soil organic matter concentrations. Soil degradation in Australia [26] is also dominated by soil erosion. The authors present evidence for three key phases of soil degradation since European settlement and show a clear link between inappropriate agricultural practices and soil degradation. Fortunately, modern agricultural practices are significantly reducing erosion losses. The contribution from Ethiopia [27] pointed out that many of their soils have been exhausted for several decades due to over exploitation and mismanagement. Using the Soil Management Assessment Framework (SMAF), they then showed that implementation of agro-forestry practices resulted in improved water entry, movement and availability through increased water-stable aggregation, soil carbon and nitrogen. The second contribution from Africa [2] concluded that the primary cause of soil degradation in SSA is expansion and intensification of agriculture in efforts to feed its growing population. The authors conclude that to mitigate soil degradation, effective solutions must support resilient systems and cut across agricultural, environmental, and socioeconomic objectives.

Two of the contributions [28,29] critically examine the factors causing soil degradation in order to highlight the interconnected nature of social and economic causes of soil degradation. They stress that as the intensity and frequency of both droughts and flooding increase, consumer confidence and the ability of crops to reach important new yield goals are also threatened. Glæsner *et al.* [29] point out that currently no European-scale legislation focuses exclusively on soil conservation. Rather, they found that three soil threats (compaction, salinization and soil sealing) were not even addressed in any of the 19 legislative policies they analyzed. In contrast, erosion, decline in organic matter, and loss of biodiversity and contamination were covered in existing legislation, but only a few directives provided targets for reducing the soil threats.

The final two papers [30,31] focus on strategies that may help prevent further soil degradation or help remediate soil resources that have experienced degradation. Lal (30) summarize strategies to reverse degradation and concludes they are to: (i) reduce soil erosion; (ii) create a positive soil C budget; (iii) improve nutrient availability; (iv) increase soil biodiversity; and (v) enhance rhizosphere processes. However Lal (30) stressed the importance of managing soil organic C as other soil properties are associated with soil organic C.

In the final paper [31], the authors examine how soil biology influences soil health and how biological properties and processes contribute to sustainability of agriculture and ecosystem services. They also critically reviewed what could be done to manipulate soil biology to: (i) increase nutrient availability for production of high yielding, high quality crops; (ii) protect crops from pests, pathogens, weeds; and (iii) manage other factors limiting production, provision of ecosystem services, and resilience to stresses such as drought.

Finally, during the review process associated with this research editorial, it was suggested that too much blame was placed on human-induced soil degradation and that natural, environmental causes were not given sufficient attention. Our initial reaction was that the individual contributions were well balanced, but since the reviewer's concern focused primarily on Andean and other tropical regions of Mesoamerica and the Caribbean Basin, and that region was not addressed in the Special Issue, we decided to provide selected examples of agroforestry projects [32–37] that have addressed soil degradation in that tropical region.

A detailed evaluation of the selected studies and numerous others in the literature is beyond the scope of this editorial, but in general, agroforestry systems have been identified as an effective way to mitigate soil degradation in the humid tropics. Agroforestry systems consisting of various tropical hardwoods, cacao (*Theobroma cacao*), and coffee (*Coffea* spp.), with and without cattle, have been evaluated to quantify their effects on soil erosion, conservation, pesticide requirements, biodiversity, nutrient leaching and other ecosystem services. Many agroforestry systems have been successful because they mimic the natural forest ecosystems that are being lost to agricultural development. However, others [36] have shown no advantage when compared with pasture areas. We suggest that as with all soil and crop management practices, the variability associated with the selected studies simply emphasizes the importance of site specific management and accounting for both anthropogenic and non-anthropogenic causes of soil degradation.

4. Summary and Conclusions

Humankind's history of making inappropriate land use and soil management decisions can be depressing, but we are optimistic that as our knowledge increases through research, sustainable development, and improved education, our collective decision-making processes will also be improved. It is our hope that the Special Issue of *Sustainability* entitled "Enhancing Soil Health to Mitigate Soil Degradation," which clearly establishes that erosion and SOM loss are almost universal indicators of soil degradation, will provide a foundation for studies designed to improve long-term soil and crop management. Implicit in all of the reports is a recommendation for coordinated planning to address physical, chemical, and biological properties and processes that are essential for restoring degraded soils and improving soil health. Addressing soil functions individually has not and will not be successful because of the multi-functionality of soil resources.

Furthermore, our climate is changing and future weather patterns are increasingly uncertain. Therefore, the improved management practices must integrate unique differences in climate and site-specific soil properties. This means that it will be impossible to develop a single, common solution or priority for mitigating soil degradation. Prevention and remediation will require integrated solutions that control all processes governing wind and water erosion, contamination, acidification, salinization, nutrient depletion, and SOM loss. For agricultural soils, management practices including the use of cover crops and/or appropriate crop residue management to reduce raindrop impact, maintain good infiltration rates, and increase soil water retention and release to plants will ultimately increase crop production, increase carbon sequestration and improve soil health. In other areas, agroforestry and planting of windbreaks has been demonstrated to be an effective means for increasing C storage, restoring soil fertility, improving nutrient cycling and availability. The common factor among these various management practices is improved soil carbon management.

Finally, we argue that continuous monitoring of soil resources is needed to document the direction and extent of change in soil resources. This information is needed by land managers and policy makers. Future research efforts should focus on how soil degradation leads to changes in soil ecosystem services, and what land management strategies make systems resilient and thus, more sustainable. Information about soils, particularly degraded soils, must be integrated into climate. This will require cooperation, innovation and communication across many groups, and specifically for soil scientists to become actively involved in trans-disciplinary studies, to broaden their focus, and to publish their results in a language that is accessible to others. One of the most promising endeavors where such interaction is desperately needed is for increased public-private research efforts focused on soil biology. We consider this of utmost importance because of the three indicator regimes (physical, chemical, and biological) influencing soil health/quality, biological relationships are by far the most complex and least understood. Fortunately, many new tools and techniques have been or are being developed to unravel these complex systems. Ultimately, this new knowledge will be used to develop appropriate, site-specific management practices that can restore degraded soils and thus enable humankind to meet rapidly increasing food, feed, fiber, and fuel needs of an expanding global population, while protecting our vital soil resources.

Acknowledgments

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Author Contributions

Both authors contributed equally to the development, writing, review and approval of the final manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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