Agron. Sustain. Dev. 29 (2009) 7–9
© INRA, EDP Sciences, 2008
DOI: 10.1051/agro:2008060

Available online at:
www.agronomy-journal.org

Agronomy for Sustainable Development

Review article

Laws of sustainable soil management

Rattan Lal*

The Carbon Management and Sequestration Center, The Ohio State University, Columbus, 2021 Coffey Road, Kottman Hall 422B, Columbus, OH 43210, USA

(Accepted 29 October 2008)

Abstract – The challenge of doubling the world's food grain production by 2030 is even more daunting because of the decrease in per capita arable land area and renewable fresh water resources; increase in risks of soil and environmental degradation; and threat of decrease in use efficiency of inputs because of the projected climate change. Thus, the need for identifying processes, practices and policies that govern sustainable management of soil resources is more critical now than ever before. The goal is to minimize risks of soil degradation by enhancing its resilience and improving ecosystem services of the finite and fragile soil resource. Here, 10 principles are given for sustainable management of soil. This report is an introductory article of the book Sustainable Agriculture, published by Springer, EDP Sciences (Lichtfouse et al., 2009).

1. INTRODUCTION

The world population of 1 million about 10 000 years ago increased to merely 1 billion by 1800. The population is projected to be 10 billion by the end of the 21st century. Almost the entire increase of 3.3 billion, from 6.7 billion in 2008 to 10 billion by 2100, will occur in developing countries where soil resources are finite and already under great stress. An unprecedented increase in agronomic productivity between the 1960s and 2000, brought about by the Green Revolution technology of growing input-responsive varieties in irrigated soils with high input of chemicals, created a false sense of security and an unnecessary complacency. Consequently, funding support for agricultural research and development has been dwindling (Anonymous, 2008). The need for a continued increase in agronomic productivity, from the cropland area and irrigation water resources already committed through increase in use efficiency of inputs with an attendant reduction in losses by erosion and leaching or volatilization, was underscored by the drastic increase in prices of food grains, e.g., wheat, rice and corn, in early 2008. The number of food-insecure people, estimated at 854 million (FAO, 2006), increased by as much as 100 million because of the increase in price of the basic food commodities.

The problem of global food insecurity may be exacerbated by the threat of global warming. The projected increase in temperature and decrease in effective precipitation in semi-arid regions may adversely impact agronomic productivity of food staples, e.g., corn, wheat and rice (Lobell et al., 2008; Brown and Funk, 2008). Examples of "tipping elements" in these important biomes include the Indian summer monsoon, and Sahel monsoon (Lenton et al., 2008). The adverse impacts of climate change on agronomic productivity may be due to a range of complex but interacting factors. Despite the positive impact of CO_2 fertilization, the net productivity may decrease because of an increase in respiration rate, drought stress and nutrient deficiency. The global energy crisis is also diverting cropland to biofuel plantations, often with positive feedback emissions of CO_2 and N_2O from soils (Searchinger et al., 2008). The competition with biofuel plantations for land is leading to new land being cleared from the tropical rainforest, often with a large carbon debt (Farzione et al., 2008).

While the debate on the magnitude and severity of global warming goes on (Florides and Christodoulides, 2008), the problems of soil degradation and desertification are exacerbated by the increasing demand on finite soil resources for the food, feed, fiber and fuel needs of the world's growing population. It is thus important to identify properties, processes and practices that affect sustainable management through setting-in-motion soil restoration trends which have minimal C and water footprints (Fig. 1). Soil degradation and restoration processes are governed by a set of laws as stated below:

2. BASIC PRINCIPLES OF SUSTAINABLE SOIL MANAGEMENT

Law #1

Soil resources are unequally distributed among biomes and geographic regions. Highly productive soils in favorable climates are finite and often located in regions of high population density, and have already been converted to managed

* Corresponding author: Lal.1@osu.edu

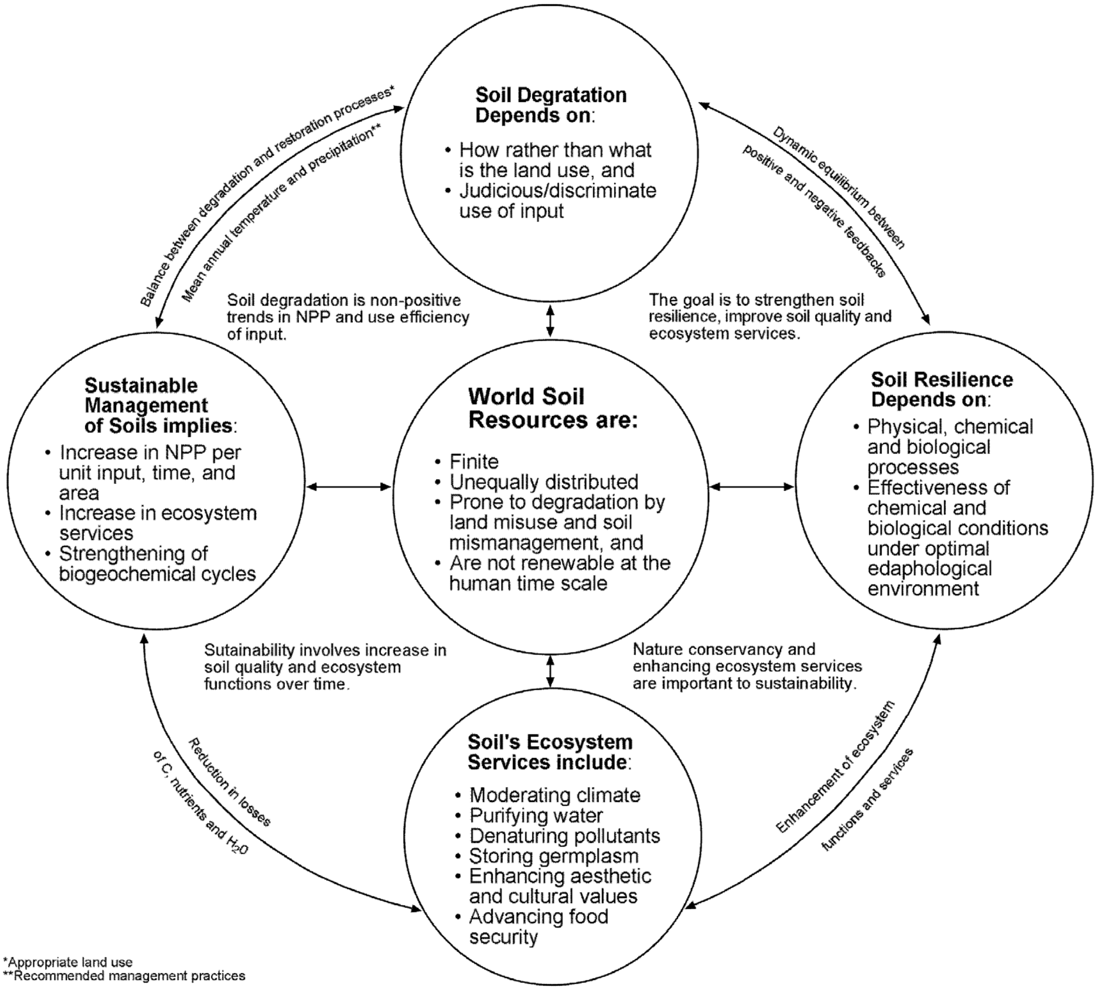

Figure 1. Properties, processes and practices which govern soil degradation and resilience, and sustainable management.

ecosystems, e.g., cropland, grazing land and pasture, forest and energy plantations.

Law #2

Most soils are prone to degradation by land misuse and soil mismanagement. Anthropogenic factors leading to soil degradation are driven by desperate situations and helplessness in the case of resource-poor farmers and smaller landholders; and greed, short-sightedness, poor planning and cutting corners for quick economic returns in the case of large-scale and commercial farming enterprises.

Law #3

Accelerated soil erosion and decline in soil quality by other degradation processes depend more on "how" rather than on "what" crops are grown. Productive potential of farming systems can only be realized when implemented in conjunction with restorative and recommended soil and water management practices. Sustainable use of soil depends on the judicious management of both on-site and off-site inputs. Indiscriminate and excessive use of tillage, irrigation and fertilizers can lead to as much as or even more degradation than none or minimal use of these technologies.

Law #4

The rate and susceptibility of soil to degradation increase with increase in mean annual temperature and decrease in mean annual precipitation. All other factors remaining the same, soils in hot and arid climates are more prone to degradation and desertification than those in cool and humid ecoregions. However, mismanagement can lead to desertification even in arctic climates, e.g., Iceland.

Law #5

Soil can be a source or sink of greenhouse gases, e.g., CO_2, CH_4 and N_2O, depending on land use and management. Soils are a source of radiatively-active gases with extractive farming which create a negative nutrient budget and degrade soil quality, and a sink with restorative land use and judicious management practices which create positive C and nutrient budgets and conserve soil and water while improving soil structure and tilth.

Law #6

Soils are non-renewable over a human time frame of decadal or generational scales, but are renewable on a geological scale (centennial/millennial). With the increase in the human population, projected to be 10 billion by 2100, restoring degraded and desertified soils over a centennial-millennial scale is not an option. Because of heavy demands on finite resources, soils are essentially a non-renewable resource.

Law #7

Soil's resilience to natural and anthropogenic perturbations depends on its physical, chemical and biological processes. Favorable chemical and biological processes enhance resilience only under optimal soil physical properties, e.g., soil structure and tilth, processes, e.g., aeration, water retention and transmission, and edaphological environments, e.g., soil temperature.

Law #8

The rate of restoration of the soil organic matter pool is extremely slow, while that of its depletion is often very rapid. In general, restoration occurs on a centennial time scale and depletion on a decadal time scale. The rate of restoration and degradation processes may differ by an order of magnitude.

Law #9

Soil structure, similar to an architectural design of a functional building, depends on stability and continuity of macro-, meso- and micropores which are the sites of physical, chemical and biological processes that support soil's life support functions. Sustainable management systems, site-specific as these are, enhance stability and continuity of pores and voids over time and under diverse land uses.

Law #10

Sustainable management of agricultural ecosystems implies an increasing trend in net primary productivity per unit input of off-farm resources along with improvement in soil quality and ancillary ecosystem services such as increase in the ecosystem C pool, improvement in quality and quantity of renewable fresh water resources, and increase in biodiversity.

Soil resources can never be taken for granted. Extinct are the once thriving civilizations, e.g., Mayan, Incas, Indus, Mesopotamia, which chose to ignore their soil resources. Given its importance to human survival and dependence of all terrestrial life, soil quality must be improved, and restored. Soils must be transferred to the next generation in a better state than when received from the previous one.

REFERENCES

Anonymous (2008) Deserting the hungry, Nature 451, 223–224.

Brown M.E., Funk C.C. (2008) Food security under climate change, Science 319, 580–581.

FAO (2006) The State of Food Security in the World, FAO, Rome, Italy.

FAO (2007) The State of Food and Agriculture. Food and Agriculture Organization of the United Nations, Rome, Italy.

Farzione J., Hill J., Tilman D., Polasky S., Hawthorne P. (2008) Land clearing and the biofuel carbon debt, Science 319, 1235–1237.

Florides G.A., Christodoulides P. (2008) Global warming and carbon dioxide through sciences, Environ. Int. 2008, 1–12.

Lenton T.M., Held H., Kriegler E., Hall J.W., Lucht W., Rahmstorf S. (2008) Tipping elements in the Earth's climate system, PNAS 105, 1786–1798.

Lichtfouse E., Navarrete M., Debaeke P., Souchère V., Alberola C. (Eds.) (2009) Sustainable Agriculture, Springer, EDP Sciences, in press.

Lobell D.B., Burke M.B., Tebaldi C., Mastrandrea M.D., Falcon W.P., Naylor R.L. (2008) Prioritizing climate change adaptation needs for food security in 2030, Science 319, 607–611.

Searchinger T., Heimlich R., Houghton R.A., Dong F., Elobeid A., Fabiosa J., Tkgoz S., Hayes D., Yu T.-H. (2008) Use of U.S. croplands for biofuels increases greenhouse gases through emissions from land-use change, Science 319, 1238–1240.