Soil Quality and Sustainable Land Management: A Review

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ABSTRACT

Soil quality is the capacity of a specific kind of soil to function to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation. Ideal soils for agriculture are balanced in contributions from mineral components (sand: 0.05–2 mm, silt: 0.002–0.05 mm, clay: <0.002 mm), soil organic matter (SOM), air, and water. However, land use type and agricultural management can be considered as the major factors that affect soil quality as a result of the change it brings on the soil's physical, chemical, and biological properties (Caravaca et al. 2002). These changed properties, in turn, affect land productivity.

Keywords: ***Soil Quality; Sustainable Agriculture; Land Management***

1. INTRODUCTION

INASMUCH as agriculture is one of the backbones of economy in whatever country (including the Philippines), there is a need to bring to light soil and its quality as it is a potent resource for sustainable agriculture.

The rapid increase in world population threatens accelerated degradation of soils and other natural resources (Power, 1996). Thus, to save agriculture for future generation, Doran and Zeiss (2000) suggest for the development of production systems that conserve and enhance soil quality. Soil quality is conceptualized as the most important linkage between the strategies for agricultural conservation management practices and achievement of the major goals of sustainable agriculture (Parr et al, 1992; Acton and Gregorich, 1995). Doran and Paikill (1994) further suggested that soil quality assessment could be used as a management tool or aid to help farmers select specific management practices and as a measure of sustainability. In short, soil quality assessment and direction of change with time, is the primary indicator of sustainable land management (Karlen et al, 1997).

There are factors influencing soil quality. Karlen et al (1992) stated that inherent interactions among the five basic soil forming factors: parent material, climate, macro- and micro-organisms, topography and time create a relatively stable soil quality that has distinct physical, chemical, and biological characteristics in response to prevailing natural or non-anthropogenic factors. However, humankind, the anthropogenic force described as a sixth soil forming factor in the basic model for describing a soil (SSSA, 1987), interacts with the non-anthropogenic factors and influences soil quality both negatively and positively. Soil and crop management practices imposed on land resources by humankind thus determine whether inherent soil quality will be lowered, sustained, or improved over relatively short time intervals. The relative importance of anthropogenic or management factors compared to non-anthropogenic physical, chemical, or biological factors will generally be determined by the function or application for which a soil quality assessment is made (Karlen, undated).

Soils vary naturally in their capacity to function; thus, quality is specific to each kind of soil. This concept encompasses two distinct but interconnected parts: inherent soil quality and dynamic quality (USDA, 2001). Inherent soil quality is governed by soil-forming processes. Characteristics like texture, mineralogy, etc. are innate soil properties determined by the five factors of soil formation – climate, vegetation, parent material, topography and time. These characteristics do not change easily. Traditionally, soil quality focuses on inherent soil properties, a concept developed to provide information on the natural ability, suitability and relative value of land for different types of agricultural production. More recently, soil quality has come to refer to the dynamic quality of soils defined as the changing nature of soil properties resulting from human use and management. This concept provides information on the impacts of agricultural practices on land and environmental degradation. It also provides an integrated assessment of soil conditions in programs that monitor a wide range of soil properties (USDA 2001; Bremer and Ellert, 2004).

Soil quality cannot be measured directly, so we evaluate indicators (Andrews and Cambardella, 2004). Indicators are measurable properties of soil that provide clues about how well the soil can function. Indicators can be physical, chemical, and biological characteristics.

Indicators of soil quality can be categorized into three general groups: physical, chemical, and biological. Physical indicators are related to the arrangement of solid particles and pores. Examples include bulk density, porosity, aggregate stability, texture, crusting, and compaction. Physical indicators primarily reflect limitations to root growth, seedling emergence, infiltration, or movement of water within the soil profile (Kheyrodin, 2014). Chemical indicators include measurements of pH, salinity, cation-exchange capacity, nutrient cycling, and concentrations of elements that may be potential contaminants (heavy metals, radioactive compounds, etc.) or those that are needed by plants in large amounts for growth and development, i.e. the primary macro-elements nitrogen (N), phosphorus (P) and potassium (K) (Kheyrodin, 2014). Biological indicators include measurements of organic matter, micro and macro-organisms, their activity, or by-products (Kheyrodin, 2014).

Land Management Practices Affecting Soil Health and Human Health

There are existing land management practices that could affect soil health and human health: Slash-and -burn, overgrazing, monocropping, excessive use of synthetic fertilizers, and excessive use of herbicides and pesticides.

The study of Kukia & Whitfield (2005) disclosed that slash-and-burn agriculture followed by tillage often lead to loss of soil organic matter and soil degradation. This practice in the Philippines is known as kaingin system.

Overgrazing occurs when plants are exposed to intensive grazing for extended periods of time, or without sufficient recovery periods (Mysterud, 2006). Overgrazing reduces the usefulness, productivity, and biodiversity of the land and is one cause of desertification and erosion. Overgrazing is also seen as a cause of the spread of invasive species of non-native plants and of weeds. Degrading land, emissions from animal agriculture and reducing the biomass in an ecosystem contribute directly to climate change. Overgrazing typically increases soil erosion (Hogan, 2009). Reduction in soil depth, soil organic matter and soil fertility impair the land's future natural and agricultural productivity. Soil fertility can sometimes be mitigated by applying the appropriate lime and organic fertilizers. However, the loss of soil depth and organic matter takes centuries to correct. Their loss is critical in determining the soil's water-holding capacity and how well pasture plants do during dry weather. Overgrazing results in increased trampling of soil by livestock, which increases soil compaction and thus, decreases the permeability of the soil. Furthermore, with more exposure of soil due to the decrease in plant biomass, the soil is exposed to increased levels of direct rainfall, creating a crust layer that is compacted and impermeable. This impermeability is what increases runoff and soil erosion (Fuls, 1992).

Monocropping is the practice of growing the same crop on the same plot of land, year after year. This practice depletes the soil of nutrients (making the soil less productive over time), reduces organic matter in soil and can cause significant erosion (SARE, n.d.). In the US, industrial farming practices often include the rotation of soybeans and corn. Technically, because two crops are in rotation, this does not get classified as a “monoculture.” However, this “simple” form of crop rotation does not provide the same benefit to the soil as do complex systems in which three or more crops are rotated over a period of one year or longer. When crops are grown in complex rotation, yields go up by as much as 10 percent in a non-drought year. Soil scientists have also discovered that monocropping alters the microbial landscape of soil, decreasing beneficial microbes and causing poor plant growth over time (Zhao, 2018).

Synthetic fertilizers have long-term negative effects. Synthetic fertilizers kill beneficial microorganisms in the soil that convert dead human and plant remains into nutrient-rich organic matter. Nitrogen- and phosphate-based synthetic fertilizers leach into groundwater and increase its toxicity, causing water pollution. Fertilizers that leach into streams, rivers, lakes and other bodies of water disrupt aquatic ecosystems (Gate, 2018). Synthetic fertilizers increase the nitrate levels of soil. Plants produced from such soil, upon consumption, convert to toxic nitrites in the intestines. These harmful nitrites react with the hemoglobin in the blood stream to cause methaeglobinaemia, which damages the vascular and respiratory systems, causing suffocation and even death in extreme cases (when blood methaemoglobin level is 80 percent or more). Synthetic fertilizers damage the natural makeup of soil in the long term. Plants that grow in overly fertilized soil are deficient in iron, zinc, carotene, vitamin C, copper and protein.

Synthetic or chemical fertilizers are also a threat to human health. According to Sharma (2020) use of excessive quantity of synthetic fertilizers are harmful for human health. It is contaminating the surface water via runoffs and its consequent effects. High levels of nitrates and nitrites in chemical fertilizer may cause some disease like hemoglobin disorders, Alzheimer's disease and diabetes mellitus. Akola (2020) disclosed that depending on the amount of fertilizer consumed, it may cause disturbances of the kidneys, lungs and liver and even cause cancer. This is due to the toxic metals that fertilizers have. Fertilizers remove the nutrients of the soil, damaging the soil and the local environment.

Pesticides are substances or mixtures of substances that are mainly used in agriculture or in public health protection programs in order to protect plants from pests, weeds or diseases, and humans from vector-borne diseases, such as malaria, dengue fever, and schistosomiasis. Insecticides, fungicides, herbicides, rodenticides, and plant growth regulators are typical examples (Alewu, 2011). Exposure to pesticides can be through contact with the skin, ingestion, or inhalation. The type of pesticide, the duration and route of exposure, and the individual health status (e.g., nutritional deficiencies and healthy/damaged skin) are determining factors in the possible health outcome. Within a human or animal body, pesticides may be metabolized, excreted, stored, or bioaccumulated in body fat (Pirsaheb, Limoee, Namdari & Khamutian, 2015). The numerous negative health effects that have been associated with chemical pesticides include, among other effects, dermatological, gastrointestinal, neurological, carcinogenic, respiratory, reproductive, and endocrine effects

Sustainable Land Practices

Today a lot of farmers have been educated as to land practices that are bound to promote sustainable agriculture.

Mulching is the use of a mulch which is a layer of material applied to the surface of soil. Reasons for applying mulch include conservation of soil moisture, improving fertility and health of the soil, reducing weed growth and enhancing the visual appeal of the area. A mulch is usually, but not exclusively, organic in nature. It may be permanent (e.g. plastic sheeting) or temporary (e.g. bark chips). It may be applied to bare soil or around existing plants. Mulches of manure or compost will be incorporated naturally into the soil by the activity of worms and other organisms. The process is used both in commercial crop production and in gardening, and when applied correctly, can improve soil productivity. Many materials are used as mulches, which are used to retain soil moisture, regulate soil temperature, suppress weed growth, and for aesthetics (Turgeon, 2009). They are applied to the soil surface, around trees, paths, flower beds, to prevent soil erosion on slopes, and in production areas for flower and vegetable crops (Blackshaw, 2007). Mulch layers are normally 2 inches (5.1 cm) or deeper when applied (Pittenger, 2002). They are applied at various times of the year depending on the purpose. Towards the beginning of the growing season, mulches serve initially to warm the soil by helping it retain heat which is otherwise lost during the night. This allows early seeding and transplanting of certain crops, and encourages faster growth. Mulch acts as an insulator. As the season progresses, mulch stabilizes the soil temperature and moisture, and prevents the growing of weeds from seeds (Louise, 1996)

Spreading manure in the farm is one sustainable practice. Most animal manure consists of feces. Common forms of animal manure include farmyard manure (FYM) or farm slurry liquid manure (Günter (2009). FYM also contains plant material (often straw), which has been used as bedding for animals and has absorbed the feces and urine. Agricultural manure in liquid form, known as slurry, is produced by more intensive livestock rearing systems where concrete or slats are used, instead of straw bedding. Manure from different animals has different qualities and requires different application rates when used as fertilizer.

For example horses, cattle, pigs, sheep, chickens, turkeys, rabbits, and guano from seabirds and bats all have different properties (Bernal, 2009). For instance, sheep manure is high in nitrogen and potash, while pig manure is relatively low in both. Horses mainly eat grass and a few weeds so horse manure can contain grass and weed seeds, as horses do not digest seeds the way that cattle do. Cattle manure is a good source of nitrogen as well as organic carbon.[4] Chicken litter, coming from a bird, is very concentrated in nitrogen and phosphate and is prized for both properties (Penido, 2017).

On-farm inputs are not only a help to farmers to cut down expenses but they are good help to fertilize soil. For example, the use of organic or natural fertilizers is one farm input. Agriculture has relied on the use of natural fertilizers -- substances that increase the nutrient levels of soil -- for most of human history. Organic fertilizers are naturally occurring substances and include biofertilizers, green manure, organic manure and compost. They slowly leach essential nutrients into the soil and improve its overall vitality with time.

Cover cropping (planting of cover crops) is another sustainable practice. In agriculture, cover crops are plants that are planted to cover the soil rather than for the purpose of being harvested. Cover crops manage soil erosion, soil fertility, soil quality, water, weeds, pests, diseases, biodiversity and wildlife in an agroecosystem—an ecological system managed and shaped by humans. Cover crops may be an off-season crop planted after harvesting the cash crop. They may grow over winter (Carlson, 2013). Although cover crops can perform multiple functions in an agroecosystem simultaneously, they are often grown for the sole purpose of preventing soil erosion. Soil erosion is a process that can irreparably reduce the productive capacity of an agroecosystem. Cover crops reduce soil loss by improving soil structure and increasing infiltration, protecting the soil surface, scattering raindrop energy and reducing the velocity of the movement of water over the soil surface (Alewell, 2015). Dense cover crop stands physically slow down the velocity of rainfall before it contacts the soil surface, preventing soil splashing and erosive surface runoff. Additionally, vast cover crop root networks help anchor the soil in place and increase soil porosity, producing suitable habitat networks for soil macrofauna (Whisler, 1990) It keeps the enrichment of the soil good for the next few years. One of the primary uses of cover crops is to increase soil fertility. These types of cover crops are referred to as "green manure". They are used to manage a range of soil macronutrients and micronutrients. Of the various nutrients, the impact that cover crops have on nitrogen management has received the most attention from researchers and farmers, because nitrogen is often the most limiting nutrient in crop production.

Often, green manure crops are grown for a specific period, and then plowed under before reaching full maturity to improve soil fertility and quality. The stalks left block the soil from being eroded. Green manure crops are commonly leguminous, meaning they are part of the pea family, Fabaceae. This family is unique in that all of the species in it set pods, such as bean, lentil, lupins and alfalfa. Leguminous cover crops are typically high in nitrogen and can often provide the required quantity of nitrogen for crop production. In conventional farming, this nitrogen is typically applied in chemical fertilizer form. This quality of cover crops is called fertilizer replacement value (Thiessen, 2005).

2 CONCLUSION

With the sustainable practices and with appropriate crops grown in the right soil type and quality increases production and therefore means augmented income among farmers that can result in poverty reduction and minimize or even end hunger in agricultural communities (Lipton, 2004).

REFERENCES

Akola, W. (2020). Chemical fertilizers. Retrieved from https://amosinstitute.com/blog/the-health-impacts-of-chemical-fertilizers/Soil and Water Cons. May-June. 243-248 soil quality indicators. Amer. 1. Alter. Agric. *7*:48-55 Soil Sci. Soc. Am. J. 63:1039-1054

Alewell, Christine (December 2015). "The new assessment of soil loss by water erosion in Europe". Environmental Science & Policy. 54: 438–447. doi:10.1016/j.envsci.2015.08.012

Are, G. (2008) Slash and burn effect on soil quality of an Alfisol: Soil physical properties. Retrieved from http://www.sciencedirect.com/science/article/pii/S0167198708001700

Bernal, M.P. (November 2009). "Composting of animal manures and chemical criteria for compost maturity assessment. A review". Bioresource Technology. 100 (22): 5444–5453. doi:10.1016/j.biortech.2008.11.027. PMID 19119002.

Carlson, Sarah (Summer 2013). "Research Priorities for Advancing Adoption of Cover Crops in Agriculture-intensive Regions". *Journal of Agriculture, Food Systems, and Community, 10,* 45-67.

Fuls, E.R. (1992). Ecosystem modification created by patch-overgrazing in semi-arid grassland. Journal of Arid Environments. *23* (1): 59–69. Bibcode:1992JArEn.23...59F. doi:10.1016/S0140-1963(18)30541-X.

Hogan, Michael (2009). Overgrazing Archived 2010-07-11 at the Wayback Machine. Encyclopedia of Earth. Sidney Draggan, topic ed., Washington DC

Kukia & Whitfield (2005). Effect of slash and burn agriculture on soil. Retrieved from https://doi.org/13.1005/ldr.3303

Lal, R. (1998). Soil quality and sustainability. p. 17-30. In R. Lal et al. (ed.) Methods for Soil Research: Washington, DC.

Mattin, M. (2013). Organic fertilizers for better soil health and human health. *Journal of Agriculture, 8,* 189-199.

Penido, Evanise (2017). "Co-pyrolysis of poultry litter and phosphate and magnesium generate alternative slow-release fertilizer suitable for tropical soils". ACS Sustainable Chemistry & Engineering. 5 (10): 9043–9052. doi:10.1021/acssuschemeng.7b01935.

Terrie, M. (2015). Natural Fertilizers for soil health and expenses reduction. *Journal of*

Agriculture and Food 10, 89-109.

Thiessen, Martens (2005). "Legume cover crops with winter cereals in southern m Fertilizer replacement values for oat". Canadian Journal of Plant Science. *85* (3): 645–648. doi:10.4141/p04-114.Till. Res. 47:157-162

Whisler, F. D. (1990). "Surface sealing and infiltration". In Anderson, M. G.; Burt, T. P. (eds.). Process studies in hillslope hydrology. Chichester, United Kingdom: John Wiley and Sons, Ltd. pp. 127–172. ISBN 0471927147.

Zhao, Qingyun et al. (2018). “Long-Term Coffee Monoculture Alters Soil Chemical Properties and Microbial Communities.” Scientific Reports 8, 6116. Retrieved from https://www.nature.com/articles/s41598-018-24537-2