EVOLUTION AND UTILIZATION OF THE SMAF FOR SOIL HEALTH ASSESSMENTS

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ABSTRACT

Soil degradation remains a global problem caused by many diverse factors. In response to this global need, farmers, ranchers, soil scientists, ecologists and many other groups interested in protecting, restoring, and/or enhancing our soil resources have recently begun to embrace the concept of soil health to achieve those goals. This presentation will focus on three critical points: (1) the modern concept of soil health did not spring up overnight, (2) critical milestones regarding soil quality/health have been achieved during the past 25 years, and (3) there are potential opportunities for using the Soil Management Assessment Framework (SMAF) to help identify the challenges and barriers that must be resolved to achieve the cultural changes in natural resource management needed to sustain soil for current and future generations. The soil quality/health endeavors throughout the 1990s and early 2000s were built on foundations laid by many excellent scientists, engineers, and scholars. Paraphrasing words once used by President John F. Kennedy, advancements in the SMAF and soil health in general can be summarized as requesting that humankind 'no longer ask what the soil can do for us, but rather what we can do to protect it!' Similarly, as our now deceased friend, mentor, and former colleague Dr. Bill Larson would often say, we must never forget that our soil resources are "the thin layer covering the planet that stands between us and starvation." My concluding question for this presentation is whether or not you are doing everything you can to ensure our fragile soil resources are being sustained for an infinite number of generations to come?

INTRODUCTION

Soil health has become a global focal point during the past five years in response to several factors including: (1) a renewed awareness of earth's rapidly increasing population, (2) greater affluence of people in many countries and thus a desire for higher protein diets, (3) the United Nations' designation of 2015 as the "International Year of Soil," (4) a proclamation by the International Union of Soil Scientists (IUSS) declaring 2015 – 2024 as the "International Decade of Soils", and (5) increasing recognition that global soil resources are continuing to be degraded by erosion and loss of soil organic matter (Karlen and Rice, 2015). Collectively these and other drivers have fueled a resurgence in public awareness of the fragility of our global soil resources.

In response to the increased interest in soil health, several public and private organizations have initiated soil health projects. Some examples include the joint Farm Foundation and Samuel Roberts Noble Foundation collaboration to initiate a 'Soil Renaissance' that according to Conklin and Buckner (2015) was designed to focus on the role of soil health in vibrant, profitable and sustainable natural resource systems. Soil Renaissance goals included increasing public awareness of soil health until it becomes the cornerstone for land use management decisions and management strategies needed to feed 9 billion people by 2050. Ultimately, the Soil Renaissance led to formation of a new Soil Health Institute (SHI), whose mission is to "safeguard and enhance the vitality and productivity of soil through scientific research and advancement." During the past five years, the USDA Natural Resources Conservation Service (NRCS) formed the Soil Health Division to complement their Soil Survey and Ecological Services Divisions in promoting care and conservation of our Nation's soil resources. This "new" NRCS soil health effort drew heavily on many of the resources developed by NRCS personnel associated with the 1990s NRCS Soil Quality Institute. I do not want to imply there was any connections between the two NRCS soil health efforts because not only was the name changed, but there were also important administrative changes. However, many of the factsheets, scorecards, and publications developed during the 1990s (e.g., rigorous reviews and testing of soil quality indicators and assessment protocols) simply had to be updated.

The Foundation for Food and Agricultural Research (FFAR), created by the 2014 Farm Bill, has also identified soil health as a critical issue by defining one of its challenge areas for research and technology development as "Healthy Soils, Thriving Farms." Furthermore, in response to 2015 being declared the International Year of Soil, the Subcommittee on Ecological Systems, Committee on Environment, Natural Resources, and Sustainability of the National Science and Technology Council developed a Soil Science Interagency Working Group (SSIWG) through the White House Office of Science Technology and Policy (OSTP) and championed development of a report entitled "The State and Future of U.S. Soils – Framework for a Federal Strategic Plan for Soil Science." The vision and mission of that interagency effort are: "A future in which the Nation manages its soils to support healthy ecosystems, vibrant communities, and a secure world" and "the establishment of a whole-of-government approach for interagency coordination and collaboration on soil research, conservation, and restoration priorities," respectively.

The Soil Health Partnership (SHP) is another very active public-private initiative. This group of industry, NGO, university, and federal scientists is funded by the National Corn Growers, Monsanto, The Nature Conservancy, The Walton Family Foundation and others. They are conducting on-farm evaluations of cover crop and other soil health promoting practices in several Midwestern states. Many university and non-government organizations (NGOs) are also coordinating research and technology transfer efforts focused on soil health and its assessment. All of these efforts are extremely valuable and can lead to many great outcomes that are crucial for protecting that "thin layer covering the planet that stands between us and starvation." However, to be most effective the efforts need to be coordinated and we must avoid thinking that concern about soil health is something new.

SOIL HEALTH – AN HISTORICAL PERSPECTIVE

One of the most humbling references documenting that humankind has been warned about the fragility of our soil resources for nearly 5000 years is a quote accredited by Hillel (1991) to Plato which states that:

> *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.*

Having worked on soil health/quality concepts for more than three decades, I frequently re-read these words whenever I begin to think that my ideas are in some way new and/or unique. I share them in this Proceedings to make others aware that although our mission to protect and enhance our soil resources is far from accomplished, we must be humble enough to recognize that none of us are pioneers in this endeavor.

MODEREN SOIL HEALTH DEVELOPMENTS

Defined as 'the capacity of a soil to function' (Karlen et al., 1997), the concept of soil quality (*i.e.*, soil health) was introduced to the scientific community more than 40 years ago (Warkentin and Fletcher, 1977). Prior to that time many excellent soil scientists (*e.g.*, Yaalon, Bidwell, Hole, Jenny & others) published several excellent articles addressing human effects on soil formation, erosion, and productivity, although none referred to soil quality or soil health *per se*. Throughout the 1990s, soil health research and technology transfer efforts were aggressively led by scientists and engineers associated with the Agricultural Research Service (ARS), the Natural Resources Conservation Service (NRCS), as well as many universities and NGOs in both the U.S. and Canada. Selected milestones include:

- 1991 – Larson and Pierce providing an initial definition of soil quality
- 1994 – Karlen & Stott publishing an initial soil quality assessment framework
- 1994 – Karlen et al. using a soil quality assessment frameworks to quantify long-term tillage and corn (*Zea mays* L.) stover harvest effects on soil properties and processes
- 1995 – Canadian scientists (Acton and Gregorich, 1995) publishing a report entitled "Health of Our Soils"
- 1996 – The Soil Science Society of America (SSSA) publishing 'Methods of Assessing Soil Quality' (Doran and Jones, 1996)
- 2004 – Andrews et al. publishing the Soil Management Assessment Framework (SMAF)
- 2005 – Development and release of the 'Cornell Soil Health Test'
- 2006 – Soil quality indicator responses within Conservation Effects Assessment Project (CEAP) watersheds being quantified to help fulfill the National Research Council (1993) recommendation that soil and water quality should be pursued as a combined agenda for American agriculture
- 2011 – SMAF used to assess the sustainability of bioenergy feedstock production practices
- 2016 – SMAF used to assess land use change effects associated with sugarcane expansion in Brazil

DEVELOPMENT OF AND OPPORTUNITIES FOR USING THE SMAF

Karlen et al. (2015) reviewed development of the SMAF as a tool for assessing soil health in order to determine if the tool could detect soil health differences associated with growing a winter triticale (*X Triticosecale* Wittmack) crop in Iowa. Since the journal containing this information may not be well known, a portion of the background information summarized for that study has been incorporated into this article which will reach a much different audience.

In general, soil quality assessment strategies were initiated during the 1990s to monitor biological, chemical and physical responses to various land uses, farming systems and management practices (Karlen et al., 1997). An important concept with regard to an evaluation being referred to as a soil health assessment is that such evaluations must consider all three response categories (*i.e*., biological, chemical, and physical) or else the assessment should simply be referred to as a 'chemical soil health,' 'biological soil health' or 'physical soil health' assessment. To help quantify the integrated response of all three factors, the SMAF was developed by Andrews et al. (2004). Subsequently, the tool has been used to quantify soil management effects for a variety of field experiments focused on cover crops and liquid manure (Jokela et al., 2009), crop rotations (Karlen et al., 2006), harvesting corn stover as a bioenergy feedstock (Karlen et al., 2011), cropping systems in the Great Plains (Liebig et al., 2006; Wienhold et al., 2006), and cropping systems in northern Colorado (Zobeck et al., 2008). Another aspect of the Colorado study was that it provided a comparison for irrigated cropping systems between the SMAF and the NRCS soil conditioning index (SCI). The cropping systems included different N fertilizer rates for no-till (NT) and conventionally tilled (CT) corn as well as NT corn grown in rotation with barley (*Hordeum distichon* L.), soybean and dry bean (*Phaeseolus vulgaris* L.). Both indexes detected differences between plots receiving very high N from those with no N, but the SMAF facilitated more detailed differentiation among crop management systems than the SCI. The SMAF separated the cropping systems into three groups and showed a decrease in overall soil quality as tillage intensity increased and surface residues decreased.

During the course of the studies described above, Wienhold et al (2009) outlined the protocol for adding new indicator scoring curves to the SMAF by developing curves for soil-test K and water-filled pore space. Similarly, Stott et al. (2011) developed and added a curve for β-glucosidase activity, bringing the total number of potential SMAF scoring curves to 14.

More recently, the SMAF was used by Veum et al. (2015) to assess soil quality for 15 different annual cropping and perennial vegetation systems typically used in Missouri and other parts of the Midwest, and to evaluate relationships among multiple measured soil quality indicators. They concluded that the benefits of conservation management practices extend beyond soil erosion reduction and improved water quality by highlighting the potential for enhanced soil quality, especially biological soil function. More specifically, they stated that implementing conservation management practices on marginal and degraded soils in the claypan region can enhance long-term sustainability in annual cropping systems and working grasslands through improved soil health. Similarly, Hammac et al. (2016) used the SMAF with 10 soil quality indicators to assess inherent and dynamic soil and environmental characteristics across crop rotations, tillage practices, and landscape positions. They found that crop selection had a greater impact on soil quality than tillage, with perennial grass systems having higher values than corn or soybean [*Glycine max* (L.) Merr.]. Also, soil samples from toe-slope positions had higher physical, biological, and overall soil quality index values than summit positions but toe-slope values were not significantly different from those of mid-slope positions. They also concluded that perennial grass systems had positive effects, corn-based systems had negative effects, and tillage practice had neutral effects on the health of the soils studied in Indiana.

In Spain, the SMAF was first used to identify the most sensitive indicators for evaluating long-term tillage and crop residue management practices within a semi-arid region (Imaz et al.,

2010) and then to re-evaluate the site three years after initiating irrigated crop production practices (Marcos Apesteguia, personal communication 2015). The results of that reevaluation confirmed that changing from non-irrigated to irrigated management changed the importance of various soil health indicators and also showed that some SMAF algorithms may need to be re-evaluated for local climate, soil, and management conditions. This appeared to be especially important for bulk density which consistently had low scoring values even though producers were achieving relatively high grain yields. In Brazil, the SMAF was used to evaluate soil health indicator changes associated with sugarcane (*Saccharum officinarum* L.) expansion for ethanol production (Cheribin et al. 2015). They reported that soils under native vegetation were functioning at 87% of their potential capacity, while pasture soils were functioning at 70% and sugarcane soils were functioning at 74% of their potential. Conversion of pasture to sugarcane induced a slight improvement in soil quality/health primarily because of improved soil fertility. Based on this study, they concluded that soil and crop management strategies could be developed to improve SQ and the sustainability of sugarcane production in Brazil.

These studies have identified several measurements that appear to be good indicators of soil health. Total organic carbon (TOC) or one of the more active carbon fractions [e.g. particulate organic matter (POM), reactive carbon, or microbial biomass carbon (MBC)], bulk density (*i.e.*, compaction), pH, aggregation, and nutrient cycling are often among the most sensitive indicators, but not always as shown by the crop rotation studies in north central Iowa and southwest Wisconsin (Karlen et al., 2006).

ANTICIPATED SMAF DEVELOPMENTS

Increased national and international interest in soil health is providing several opportunities to reevaluate and improve the SMAF. The tool is being used to help analyze the on-farm data being collected for the SHP cover crop effects on soil health project. It is also being examined by the NRCS Soil Health Division for its utility in a national soil health survey. Finally, a Materials Transfer Agreement is being initiated by the ARS to link together not only other U.S. government agencies, NGOs, and Brazilian soil scientists through Embrapa (the Brazilian equivalent of the USDA) but also the private sector through Climate Corp and possibly other groups. Without question, these efforts are in their infancy, but currently the SMAF is the only comprehensive tool that has been evaluated internationally and shown to effectively integrate soil biological, chemical, and physical indicator information. The scoring algorithms are sensitive to soil morphology, analytical methods of analysis, climate, cropping sequence, mineralogy, slope and time of sampling. Therefore, soil fertility and plant nutrition groups such as the International Plant Nutrition Institute (IPNI), perhaps working through the Western Region Nutrient Management Coordinating Committee (WERA-103) and/or other regional groups, may have an interest in these efforts, since the soil testing community will certainly have a dominant role in future soil health assessments with or without the SMAF.

SUMMARY

This report supports the presentation given at the 2017 Western Nutrient Management Conference in Reno, Nevada and provides an overview and update on the soil management assessment framework (SMAF). Its origin, past uses in the U.S. and other countries, as well as planned evaluations to improve the tool for soil health assessments are briefly reviewed. As stated by Karlen et al. (2008), meaningful SMAF assessments can be made with only five or six indicators provided they reflect soil biological, chemical, and physical properties and processes.

This means that data collected from almost any type of soil and crop management study at on-going or new research sites could be used with the SMAF to provide soil health assessments without requiring major fiscal and labor resource investments beyond that already being committed by the individual researchers. Once again, I invite members of the WERA-103 and other soil-testing groups to learn more about the SMAF and help develop an improved second generation SMAF that can help all of us protect and sustain our fragile soil resources.

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