Conservation Tillage and Soil Tilth: A Sustainable Combination

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Abstract

A need for favorable soil tilth to sustain productive agriculture has been recognized for many years, but quantitatively soil tilth remains a mystery. Soil tilth is dynamic, temporal, and affected by many factors. Measurements including aggregation, bulk density, porosity, structure, infiltration rates, surface roughness, and relative tendency to puddle, slake, or form surface crusts are used to characterize soil tilth. A recognition that soil tilth has a role in long-term soil productivity and sustainable agriculture, resulted in establishment of the National Soil Tilth Laboratory (NSTL) in Ames, IA Objectives of this report are to share the vision that scientists at the NSTL have with regard to soil tilth research priorities, identify cooperative research opportunities, and to discuss their relationship to conservation tillage throughout the southern U.S.

Introduction

Soil tilth is a very old concept that describes the soil condition created by an integration of the physical, chemical, and biological processes occurring within the soil matrix. Karlen et al. (1990) suggested changing the Soil Science Society of America definition of soil tilth to "the physical condition of a soil described by its bulk density, porosity, structure, roughness, and aggregate characteristics as related to water, nutrient, heat and air transport; stimulation of microbial and micro-fauna populations and processes; and impedance to seedling emergence and root penetration". They also defined *tilth forming processes* as "the combined action of physical, chemical, and biological processes that bond primary soil particles into simple and complex aggregates and aggregate associations that create specific structural or tilth conditions".

Soil tilth, tillage, and crop rotation are factors that are considered to affect soil productivity and sustainability. Whiteside and Smith (1941) stated that from the earliest days of agriculture, gradual changes in soil productivity had been observed because of crop production. They found that cropping systems had a great influence on the amount and direction of change in N and organic C concentrations, and that crops differed in their ability to preserve, amend, or deplete soil productivity.

Optimum seedbeds became synonymous with optimum soil tilth because of the difficulty in quantifying desireable tilth characteristics. Multiple tillage operations were considered essential to create a favorable seedbed, to achieve good soil-seed contact, and to ensure rapid, uniform crop emergence. After World War II, Melsted (1954) addressed the effects of tillage on tilth and suggested that by substituting capital for labor, the science of farming could replace the art of farming. He suggested that by using fertilizer N and reduced tillage, erosion could be controlled, organic matter increased, and optimum soil tilth developed.

The emotional perception that intensive tillage created good tilth was evident in early soil management information. Fream (1890) stated that in the minds of tillers, being told a soil is "open, free-working, mellow, or in good heart" makes one feel good, but if a soil is "hungry, stubborn, stiff, cold, or unkind" we immediately perceive it as being nonproductive. Recognizing that many people perceive that intensive tillage is essential for crop production makes it easier to understand the resistance that Jackson (1980) identified with regard to farmers adopting changes in soil management such as implementation of no-till or other conservation tillage practices. Fortunately, through meetings such as the Southern Conservation Tillage Conference, U.S. farmers have been provided information and techniques that can correct the misconception that intensive tillage is essential.

The objective of this presentation is to share the vision that scientists at the National Soil Tilth Laboratory (NSTL) have with regard to soil tilth research priorities and their relationship to conservation tillage.

Importance of Soil Tilth

Soil tilth is important because it affects all processes occurring in, the soil matrix, including crop growth. Soil tilth is often inversely related to soil strength which is associated with aggregate disintegration. As tilth is degraded, aggregate stability is often decreased

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allowing surface crusts and dense, compacted zones to form. These conditions increase the potential for soil erosion and often affect plant growth by reducing emergence, aeration, root growth, and total biomass production. This may decrease the amount of carbon returned to the system and further decrease aggregate formation. Degradation of tilth can be accelerated by poor management decisions such as performing an excessive number of unneeded or poorly timed tillage operations.

Tilth affects crop growth by influencing infiltration, movement, and retention of water within the soil profile. It influences chemical and biological processes occurring within the soil matrix by influencing aeration, heat transport, and profile water relationships. Tilth interactions are often complex and temporal. They are affected by many factors but have significant impact on crop growth, nutrient and water use efficiencies, and profitability of crop production. One example is mineralization organic N sources including organic matter, manure, sludge, or crop residue into inorganic N forms that can be cycled through subsequent crops or lost through leaching and denitrification.

Many soil chemical and biological processes also influence degradation of herbicides, insecticides, and fungicides (Moorman, 1989). When combined with water movement within the profile, these processes influence runoff, erosion, percolation, and ultimately transport of agrochemicals from or through the soil matrix and into surface or groundwater resources. This suggests that developing an interdisciplinary understanding of soil tilth is a high priority soil-related research topic for economically and environmentally sustainable agricultural growth.

Factors Affecting Soil Tilth

Many factors, including compaction by agricultural equipment, tillage, crop rotation, application of fertilizer and lime, freezing and thawing, wetting and drying, earthworms, arthropods, and other soil insects have been shown to influence soil tilth (Karlen et al., 1990). Soil organic matter is also a primary factor needed to sustain or improve soil tilth.

Developing management practices to create desired soil tilth conditions is difficult because tilth is a dynamic condition and processes that affect it are poorly understood. Research is needed to quantify the mechanisms through which soil organic matter, soil flora, fauna and microorganisms, as well as other physical, chemical, and biological processes affect soil tilth. This information is needed to better understand relationships among tilth and soil management problems, such as surface and groundwater quality, crop water use efficiencies, and long-term productivity, in order to quantitatively define and prescribe practices for sustainable agricultural growth.

National Soil Tilth Laboratory

History: Need for a National Agricultural Research Service Laboratory to study soil tilth was identified by the 86th U.S.Senate in Senate Document No. 59 (U.S. Senate, 1959). Planning for the laboratory involved many people, from many disciplines, and from all parts of the U.S. All efforts were fulfilled when the NSTL was dedicated on 6 July, 1989, thirty-years after it was officially recommended.

Mission: The mission of the NSTL, stated at the dedication is "to gain an understanding of the fundamental processes that occur in the soil as a result of physical, chemical, and biological interactions and tillage operations, and the effect of these processes on soil structure, environmental quality, and sustainability of agriculture." This mission emphasizes that soil tilth is considered to be a basis for sustainable agriculture in the United States and around the world.

Research Programs: The NSTL will provide a focal point for a national research initiative and program on soil tilth. The research focus will be on quantitatively understanding soil tilth and its relationship to national problems including issues such as groundwater quality and conservation tillage. In cooperation with scientists located at other ARS, Soil Conservation Service (SCS), State Experiment Station (SES), and Cooperative Extension Service (CES) locations throughout the U.S., research will be conducted to develop basic principles that can be integrated into complete management systems for improving, maintaining, or restoring soil tilth on agricultural lands. This program will provide many opportunities for cooperatively developing conservation tillage practices that sustain or improve soil tilth. The NSTL research program will provide a mechanism for interfacing state and federal research activities and opportunities for visiting scientists and graduate student programs.

Facility: The building has four levels, each with approximately 20,000 ft^2 of floor space. There are 43 laboratories and 52 offices. A unique feature of the NSTL is an indoor rhizotron that will allow research in which both above- and below-ground environments can be controlled. Undisturbed soil monoliths and reconstructed soil profiles can be studied in four chambers designed to grow plants to maturity. The building has a "terminal velocity tower" for research that requires rainfall simulation. There are laboratories with specialized analytical equipment, including a carbon-nitrogen-sulfur analyzer, an inductively coupled plasma spectrometer, an image analyzer, and an Instron universal testing instrument. Several laboratories are also being equipped with state-of-the-art robotics, gas chromatographs, high-pressure liquid chromatographs, and mass spectrometers to analyze for agrochemical residues and their decomposition products in soil, plant, and water samples.

When fully operational, there will be a research staff of 20 to *25* scientists. Graduate students associated with Iowa State University, post-doctoral research associates, and visiting scientists will be important contributors to interdisciplinary research teams within the laboratory. The teams will have active cooperation with several other research programs and scientists from other organizations at locations throughout the United States and around the world.

Research Approach: Interdisciplinary teams at the NSTL are conducting research to define and investigate physical, chemical, and biological factors that influence soil tilth. Those factors are then being integrated into farm management practices that can be used to develop sustainable agricultural production systems. This approach will provide the coordinated effort needed to quantitatively understand tilth and to learn how to maintain and improve tilth and thus optimize productivity and environmental quality. Typical soil physical investigations include: (a) developing techniques for measuring soil structure to better predict solute movement through soil, soil erosion, water infiltration, root growth, energy exchange at the soil surface, and tillage processes; (b) quantifying effects of tillage or wheel traffic on soil aggregation and formation or modification of soil pores; and (c) defining how tillage affects movement of agricultural chemicals from the zone of soil managed for crop production.

The soil chemical studies include: (a) measuring interactions among chemical and biological processes resulting from tillage and crop management systems that affect availability, sorption, transformation, and losses of agricultural chemicals; (b) assessing effects of different long-term cropping histories and agricultural management systems on soil chemical properties; and (c) identifying soil nitrogen-crop-tillage interactions that are required to synchronize soil nitrogen transformations and applied nitrogen with plant nitrogen requirements.

Biological investigations include: (a) quantifying the distribution, roles, and modes of action that earthworms, insects, and plant roots have on the development of macropores and chemical movement under various short- and long-term management practices; (b) quantifying effects of microbial and earthworm populations and distributions on the physical-chemical-biological interactions within the soil volume; and (c) developing integrative models for soil biological components related to tillage and management practices that predict nutrient movement, pesticide degradation, and groundwater quality.

Summary and Conclusions

The United States has a tremendous soil resource, but poor soil and crop management practices in some areas are allowing it to diminish by failing to control erosion, compaction, and other forms of soil deterioration. These processes affect soil tilth which influences almost every physical, chemical, and biological process occurring within the soil. The interaction between soil management and soil tilth has been recognized in a general manner for centuries, but now there is an opportunity to quantify effects of various soil management practices on soil tilth through research programs at the NSTL. One result of these new research efforts will hopefully be development and implementation of conservation tillage practices that improve soil tilth. Achieving that goal will create more economically and environmentally sustainable crop production systems.

Interpretive Summary

The USDA-Agricultural Research Service (ARS) has established the National Soil Tilth Laboratory (NSTL) in Ames, IA. This is important because good soil tilth is thought to be important for maintaining long-term soil productivity and sustained agricultural growth. This paper will be presented at the Southern Regional Conservation Tillage Conference. This forum will also provide an opportunity to discuss the Aldo Leopold Center for Sustainable Agriculture that the State of Iowa established on the Iowa State University campus. Cooperatively, the NSTL and the Leopold Center will provide many opportunities for cooperative research and generation of information for farmers and the general public. This report outlines initial research programs that will establish soil tilth as a fundamental basis for an economically and environmentally sustainable agriculture.

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