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SOIL TILTH AND SUSTAINABLE AGRICULTURE

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Soil tilth is defined as the "physical condition of soil as related to its ease of tillage, fitness as a seedbed, and its impedance to seedling emergence and root penetration." Sustainable agriculture has been defined in Iowa as "the appropriate use of crop and livestock systems and agricultural inputs supporting those activities which maintain economic and social viability while preserving the high productivity and quality of Iowa's land." Thus, it is not possible to discuss sustainable agriculture without considering soil tilth. Development of a sustainable agricultural system requires a viable and stable soil resource, so we will explore linkages between the two concepts.

Karlen et al. (1989) proposed in a recent review that the definition of soil tilth be broadened to include the chemical and biological components. They defined soil tilth as "the physical condition of the 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 microfauna populations and processes; and impedance to seedling emergence and root penetration." As a soil property, tilth is more easily described than quantified. The processes which lead to development and maintenance of tilth are not clearly understood. We do know, however, that factors which lead to good tilth are closely associated with factors linked to sustainable agriculture.

The physical, chemical, and biological processes that occur within soil are complex and interrelated. A change in one process may have a large impact on the other two. These interrelationships have not been clearly defined nor quantified for various cropping systems. As the linkage between soil tilth and sustainable agriculture is developed, seasonal dynamics become more important and the complexity of the picture begins to increase. The problem also emerges as one which is interdisciplinary and multidisciplinary because of the need to fully understand each component in a complex agricultural system.

The soil volume can be considered to be composed of the following two layers: The upper zone, which we manage through tillage, addition of soil amendments, chemicals, fertilizers, manures, lime, incorporation of crop residues, and planting of seed; The lower zone which is available to the plant through growth of roots which extract water and nutrients that the plant utilizes for growth.

The soil volume is therefore composed of the managed and utilized zones. Each zone may have a positive or negative impact on the other through a variety of factors. The managed zone is where we can develop and sustain tilth and where the impacts of different management systems can be easily seen by producers.
Physical processes

The physical processes that occur within soil are related to soil structure or aggregates at the surface. Soil that has aggregate stability is able to maintain a higher infiltration rate because of a more stable surface structure and can generally provide more water to plants throughout the growing season. This soil is also less susceptible to erosion and thus fewer nutrients and chemicals are moved from the field. A soil with residue cover is also less susceptible to breakdown of aggregates because raindrop forces are dissipated in the residue rather than on the soil. A residue cover also reduces the rate at which soil water is evaporated from the surface leading to a reduction in diurnal soil temperature variation in the upper portion of the profile. Heavy residue on the soil can lead to cooler soil temperatures, particularly at northern latitudes where soil temperature is often a limitation to plant growth. However, there is little data throughout the fall and winter to determine the seasonal impact of different residue levels created by various management practices. This information could lead to an improvement of our management practices. The addition of crop residue to the soil also provides a food source for the soil fauna, but changes in the soil microclimate may have an even greater impact if they create a more favorable environment in which the microfauna can reproduce.

Roots penetrate the soil creating channels as they extract both water and nutrients. The channels often remain after previous crops die and may provide avenues for current crop roots to move through as well as channels for water and chemical movement. Unfortunately, root systems are difficult to measure and it has not been possible to fully understand what causes limitations to root growth in the field. Old root systems also provide a food source for soil fauna that must not be overlooked as part of the management scheme. Crop rotations may increase diversity in types of root channels and lead to a more stable soil ecosystem. These aspects will require a very concentrated research effort in order to develop a complete understanding of factors involved and variation in root growth and development for different soils and climates.

Chemical processes

Sustainable agriculture suggests that the farming system be capable of supplying essential plant nutrients without overapplication of chemicals. By more fully understanding the dynamics of farming systems relative to chemical processes and transformations within the soil, it should be possible to develop systems that have a higher nutrient use efficiency. We have developed farming systems that have a high rate of water use efficiency, i.e., the rate of dry matter or harvestable yield produced per amount of water used by the plant, and I believe the concept could be more effectively utilized in our research on plant production and nutrient availability. This information should be forthcoming as we gain a better understanding of the soil as an ecosystem.

Chemical transformations of nitrogen are the most understood within the soil complex. However, we need to focus our attention on aspects related to improving availability of all nutrients throughout the growing season and the timing of nutrients relative to crop requirements. With emphasis on nitrate movement through the soil, it is necessary to more completely identify factors related to
nitrogen dynamics under different cropping systems. This includes use of legume and catch crops in rotations. Their impact on soil structure, soil microorganisms, and contribution of fixed nitrogen need to be quantified. The total nutrient complex within the soil needs to be more carefully defined and understood in the context of crop rotations, cultivated monocultures, and managed grasslands. Studies will include both macro-nutrients as well as micronutrients.

**Biological processes**

The least understood processes occurring within the soil are the biological complex. Those components include the mycorrhizae, microbes, and the larger earthworms and soil insects. Population dynamics of these organisms are not well understood, but they have been associated with soil aggregation. Polysaccharide complexes that are exuded by these organisms may play important roles in the soil binding process. Efforts will be made to quantify how different organisms and soil material interact to form stable aggregates. Formation of channels by earthworms and soil insects may allow for selective movement of water through the soil profile. However, effects on movement of chemicals through these macropores are not well understood at this time.

Soil biology includes the root system, pathogens, and fungi that exist within the soil. Dynamics of these components will have to be quantified if we are to develop sustainable agricultural systems. The plant pathogen complex may be changed if crop residues increase the time that the soil surface is wet. These aspects will have to be incorporated into studies on sustainable agriculture.

**Agricultural systems**

Development of sustainable agricultural systems will require a multifaceted approach. The physical, chemical, and biological processes that occur within soil and contribute to development and maintenance of soil tilth are also factors that are necessary for a sustainable agricultural system. To fully integrate this information into a form useable by producers will require sophisticated, dynamic and complex mathematical models of complete agricultural systems. These models may have to be developed on an individual field initially and then extended to a farm before substantial progress can be made. It will also require that information from a variety of disciplines be integrated to understand complex interactions that occur within farming systems.

Sustainable agriculture may become the new "conventional" agricultural system provided the dynamics of many factors can be understood. Research teams that focus on understanding the interactions and the dynamics of the farming system will have to be developed. The soil, climate, and plant interactions that occur provide a challenge for agricultural scientists to address, but, the information gathered will be rapidly used and practiced.

**References**