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Soil Responses to Tillage-Induced Disruption and Consequences for Conservation Practices

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Abstract: -

The influence of tillage implements on soil physical characteristics has been extensively investigated. Nevertheless, the soil conditions produced by a particular tillage operation are highly variable because they depend on both implement-related factors, such as tillage depth and operating speed, and soil-related factors, including moisture status, texture, and surface residue cover. As a result, it is difficult to clearly characterize, and even more challenging to accurately predict, soil property changes associated with a specific tillage practice. This report synthesizes the range of responses of selected soil properties documented in earlier tillage research and highlights the key factors that should be taken into account when developing reliable models to predict tillage effects on soil attributes relevant to soil and water conservation. The analysis focuses on soil mechanical properties, such as surface roughness, aggregate size distribution, and bulk density, as well as hydraulic properties and processes, including water retention, saturated hydraulic conductivity, infiltration, and evaporation. To ensure that future tillage studies contribute effectively to the development of robust relationships between tillage practices and soil properties, research reports should provide detailed information on soil classification, texture, moisture status (or timing of rainfall), bulk density, mechanical resistance, and organic matter content, along with tillage type, depth, and speed of operation. In addition, details on the preceding crop, residue availability, and prior soil management history, such as compaction status or irrigation regime, should also be clearly documented.

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Introduction:

Tillage in agricultural systems refers to the deliberate, usually mechanical, alteration of soil characteristics to create favourable conditions for crop production. Soils are tilled for several purposes, including the suppression of weeds, incorporation of fertilizers, pesticides, and crop residues, and the adjustment of soil physical attributes to enhance seedbed quality, plant growth, and crop yield. However, the soil environment produced by a particular tillage practice is highly variable, as it is influenced by both implement-related factors, such as the depth and speed of operation, and soil-related factors, including moisture status, texture, and surface residue cover. Consequently, the soil conditions created by a specific tillage operation are difficult to clearly describe and even more challenging to accurately predict.

This report aims to synthesize the range of responses of selected soil properties documented in earlier tillage research and to identify the key factors that should be taken into account when developing reliable models to predict the impacts of tillage on soil characteristics. The discussion primarily focuses on the immediate effects of tillage, as changes occurring after tillage are often driven by processes such as wetting and drying cycles, freezing and thawing, and subsequent field operations rather than by tillage itself. Nevertheless, where relevant information is available, changes in soil properties over time are also considered.

Mechanical properties

Surface microrelief, or soil surface roughness, creates small depressions that temporarily retain water at the soil surface, allowing greater opportunity for infiltration while reducing overland water flow. Increased surface roughness also contributes to the control of wind erosion. In soils that are highly susceptible to wind erosion, practices such as deep tillage or chisel tillage are often employed to expose non-erodible soil materials at the surface, thereby enhancing erosion resistance. Additionally, tillage operations that disrupt surface crusts and increase surface roughness are sometimes adopted as emergency measures to mitigate wind erosion.

Aggregate size distribution

Surface soil aggregates play a critical role in regulating water infiltration and minimizing erosion. To sustain adequate infiltration and reduce soil loss, aggregates must be stable in water so that soil dispersion and the formation of surface seals are limited. The size of water-stable aggregates generally has little influence on infiltration and water-erosion control, except that very small aggregates tend to block soil pores, thereby reducing infiltration rates. Aggregates smaller than 0.25 mm, along with individual soil particles, are particularly important in restricting infiltration because they promote pore clogging and the development of surface seals. These fine particles are also more easily transported by runoff, increasing the risk of erosion.

While the size of water-stable aggregates has a limited effect on erosion by water, the size of dry aggregates strongly influences susceptibility to wind erosion. Aggregates smaller than 0.84 mm are generally considered vulnerable to wind transport. The stability of soil aggregates in water is influenced by factors such as organic matter content and clay concentration, among others. Therefore, tillage practices that redistribute organic matter, including crop residues, and clay within the soil profile can significantly affect the water-stable aggregation of soil layers.

For instance, Unger et al. (1973) reported that water-stable aggregation in Pullman clay loam was higher, or tended to be higher, within the 0–75, 75–150, and 150–225 mm soil depths when wheat (Triticum aestivum L.) residues were incorporated to a depth of 120–150 mm using rotary or disk tillage, compared with treatments where residues were buried by listing or moldboard plowing or removed by burning. At depths of 225–300 mm, where clay content was greater but organic matter and residue levels were lower, water-stable aggregation was generally similar to that in the upper layers. Additional studies indicate that reduced-tillage systems, such as no-till or direct drilling, typically promote greater water-stable aggregation than intensive tillage practices, and that aggregate stability tends to improve over time under reduced tillage (Maillard and Vez, 1982). In general, coarse-textured soils exhibit lower levels of water-stable aggregation than fine-textured soils.

Soil water retention

Soil water retention is primarily governed by total porosity and the distribution96 of pore sizes within the soil. Consequently, any changes in porosity and pore structure caused by tillage or other forms of soil disturbance can modify the soil's capacity to retain water. Tillage alters porosity and pore size distribution mainly through its effects on soil bulk density. A reduction in bulk density leads to an increase in total porosity, which in turn enhances water retention at higher soil water potentials while reducing the amount of water held at lower potentials. The magnitude and direction of this response, however, are influenced by soil texture. For instance, Unger (1975) reported that disruption of the natural soil structure reduced water retention in coarse-textured soils but increased it in fine-textured soils when compared with undisturbed soil cores at a matric potential of −0.033 MPa. At a lower matric potential of −1.5 MPa, disturbed soils of all textures retained slightly more water than undisturbed soils, although the relative increase was more pronounced in coarse-textured soils than in fine-textured ones. In addition to textural effects, tillage can further modify soil water retention by incorporating crop residues or by redistributing sand, silt, and clay particles through the mixing of material from different soil horizons.

Saturated hydraulic conductivity

Changes in soil pore size distribution resulting from tillage lead to corresponding alterations in saturated hydraulic conductivity (Ksat). Soil loosening generally enhances Ksat, whereas compaction caused by wheel traffic during or after tillage operations reduces Ksat compared with pre-tillage conditions. In addition, wheel-induced compaction below the depth of shallow tillage can decrease Ksat in subsurface layers beneath the tilled zone. Cassel and Nelson (1985) observed positional effects on Ksat under conventional, chisel plow, and subsoil-bed tillage systems in a Norfolk loamy sand soil containing a tillage pan. Their results showed that Ksat varied both spatially and temporally depending on sampling position and soil depth, while tillage treatment itself did not produce a consistent overall effect. Consequently, variations in Ksat measured within the 0–140 mm soil layer were more strongly influenced by sampling position within a given tillage system than by the specific tillage method applied. Across all tillage practices, areas subjected to wheel traffic exhibited the lowest Ksat values. At depths of 140–280 mm, positional differences in Ksat were not statistically significant.

Prediction of tillage effects

Attempts to predict or model certain tillage–soil interactions, such as soil–plant relationships, soil–implement dynamics, and the draft forces required for tillage, have met with moderate success. In contrast, efforts to quantitatively model the effects of tillage on the soil physical properties discussed in this report remain limited or largely unexplored. While experienced practitioners can often anticipate some tillage outcomes in a qualitative sense, accurate quantitative predictions of soil physical conditions following tillage are constrained by an incomplete understanding of how soils deform and fail during tillage operations. Several tillage-related factors influence soil physical properties, including prior loading history, the nature of the applied stress, the rate at which stress is imposed, and the initial physical condition of the soil (Hadas et al., 1988). In addition, soil-specific characteristics such as texture, clay mineral composition, moisture status, depth, and organic matter content also play a significant role in determining the soil properties that result from tillage. Adequate knowledge of these factors is essential for the development of robust, quantitative models capable of predicting tillage-induced changes in soil physical properties.

Among soil-related variables, moisture content at the time of tillage is one of the most influential determinants of tillage effects. Although numerous studies have examined tillage impacts on soil properties, information on soil water content at the time of tillage is often missing. Furthermore, moisture levels within the tilled layer are rarely uniform and typically vary with depth. As a result, a critical parameter needed for interpreting and predicting tillage effects from earlier studies is frequently unavailable. While it may sometimes be possible to approximate general moisture conditions based on cropping history or regional climate, such details are seldom reported. Consequently, the potential to establish reliable predictive relationships between tillage practices and soil physical properties using existing literature is limited, underscoring the need for more comprehensive and systematically reported research.

To enhance the usefulness of future tillage studies, researchers should provide detailed information on key soil and management variables, including: (1) soil classification; (2) soil texture, expressed as sand, silt, and clay proportions; (3) soil moisture content at the time of tillage or timing of rainfall events; (4) bulk density; (5) mechanical resistance; (6) organic matter content; (7) tillage method; (8) depth of tillage; (9) the preceding crop and the amount of crop residue present; and (10) prior soil management history, such as compaction status and irrigation regime. In most cases, the nature of the tillage action whether inversion, mixing, loosening, or crushing is more critical than the specific implement used, although details regarding the implement, operating speed, and related parameters should still be clearly described. It should also be noted that some implements can induce more than one type of tillage action (Krause et al., 1984).

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