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Review

Soil friability: A review of the concept, assessment and effects of soil properties and management

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ABSTRACT

This review gathers and synthesizes literature on soil friability produced during the last three decades. Soil friability is of vital importance for crop production and the impact of crop production on the environment. A friable soil is characterized by an *ease* of fragmentation of undesirably large aggregates/clods and a *difficulty* in fragmentation of minor aggregates into undesirable small elements. Soil friability has been assessed using qualitative field methods as well as quantitative field and laboratory methods at different scales of observation. The qualitative field methods are broadly used by scientists, advisors and farmers, whereas the quantitative laboratory methods demand specialized skills and more or less sophisticated equipment. Most methods address only one aspect of soil friability, i.e. either the strength of unconfined soil or the fragment size distribution after applying a stress. All methods have significant advantages and limitations. The use of a mixture of qualitative and quantitative methods to get a comprehensive and adequate assessment of soil friability is recommended. Poor friability can be experienced if soil is either too wet or too dry and there is a range in water contents for optimal friability. There is a strong need to get more detailed knowledge about effects of soil water content on soil friability and especially to be able to quantify the least limiting water range for soil friability and therefore soil tillage. A strong relationship between organic matter and friability has been found but it is not possible to identify a specific lower critical level of organic matter across soil types. Sustainable management of soil requires continuous and adequate inputs of organic matter to sustain or improve soil friability. Intensive tillage and traffic in unfavorable conditions threatens soil friability and may initiate a vicious cycle where increasingly higher intensity of tillage is needed to produce a proper seedbed.

Contents

Abbreviations: E, rupture energy; FSD, fragment size distribution; GMD, geometric mean diameter; MWD, mean weight diameter; S, index of soil physical quality; SOM, soil organic matter content; SWRC, soil water retention curve; Y, tensile strength; w, gravimetric water content; θ, volumetric water content; θ_{DL}, dry limit volumetric water content for soil fragmentation; θ_{INFL}, volumetric water content at inflation point; θ_{OPT}, optimal limit volumetric water content for soil fragmentation; θ_{PL}, plastic limit volumetric water content; θ_{WL}, wet limit volumetric water content for soil fragmentation; $\Delta\theta_{RANGE}$, range in soil water content for tillage; Ψ, soil water matric potential.

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1. Introduction

Soil friability is a key soil physical property yielding valuable information on the ease of producing a favorable seed—and root beds during tillage operations. Therefore, soil friability is a crucial soil property in relation to the ability of soil to support plant growth and to minimize the energy required for tillage.

The awareness of soil friability is growing, both in practice and in soil science. The topic has interested soil scientists for centuries (e.g. Christensen, 1930), but it was the paper by Utomo and Dexter (1981) that significantly put the topic on the soil science agenda. The interest in the topic has recently escalated according to citations registered in the ISI Web of Science database (*Thomson Reuters*). The increased interest must be viewed in the light of the present renewed focus on global food security (FAO, 2009) together with a focus on fossil fuel consumption and greenhouse gas emissions in crop production. Certainly, the demand for well-functioning arable soils is rising to meet the global challenges. However, the threats to soil quality appear also to be on the increase due to climate change and changes in soil management. In North-Western Europe soil compaction, loss of organic matter and soil erosion are the main threats to soil quality and, in particular, to soil friability. The soil organic matter content is expected to decrease with increased temperatures and the expected higher frequency of intensive rainfall will increase the risk of water erosion. In North-Western Europe, the expected increase in winter precipitation will limit the window for timely traffic and tillage in the spring and thus increase the risk of severe soil compaction.

Soil friability is related to brittle fracture of soil as described by Braunack et al. (1979) and Dexter and Watts (2000). Brittle fracture results from the progressive development of cracks ending with a crack opening and a sudden loss in strength (Hatibu and Hettiaratchi, 1993). The propagation of cracks in an unconfined stressed soil depends on the density and the morphology (connectivity, orientation) of the air-filled pores and the strength at the crack tips as defined by Hallett et al. (1995a,b). The occurrence and nature of cracks in the soil depend on basic soil properties (texture, clay mineralogy), climate (cycles of wetting–drying and frost–thaw), soil biological activity as well as tillage and traffic. This review gathers and synthesizes literature on soil friability produced during the last three decades since the paper of Utomo and Dexter (1981). The objectives are to: 1. review the methodology to assess soil friability, 2. describe effects of basic soil properties affecting soil friability with special focus on the soil water regime, 3. evaluate the effects of soil management, and 4. identify knowledge gaps.

2. Soil friability—the concept

The term soil friability has been discussed, defined and redefined by soil scientists for decades. Christensen (1930) defined it as "*the ease of crushing, crumbling or rubbing apart of the particles of which it is composed*" and thus emphasized the tendency of unconfined soil to crumble and break down. Utomo and Dexter (1981) elaborated on this definition and came up with the present widely accepted definition of the concept: "*Soil friability: the tendency of a mass of unconfined soil to break down and crumble under applied stress into a particular size range of smaller fragments*". Therefore, a friable soil is characterized by an *ease* of fragmentation of undesirably large aggregates/clods and a *difficulty* in fragmentation of minor aggregates into undesirable small elements. Excessively small aggregates (<0.5–1 mm) enhance soil erodibility and may impede seedling emergence as they increase the risk of surface crusting. But what is the ideal size distribution of soil aggregates in the seed and rooting bed? Karlen et al. (1990) stated that a soil with a good soil tilth "*usually is loose, friable and well granulated*". This qualitative perception of a "crumb structure" as the optimal environment for plant growth is supported by empirical data. Braunack and Dexter (1989) concluded in a review that the optimal seedbed (i.e. the soil layer that has been tilled to a condition to promote seed germination and the emergence of seedlings) is produced by 0.5–8 mm aggregates. Berntsen and Berre (1993) concluded that an optimal seedbed for cereals is characterized by about 50% of the aggregates by weight being in the 0.5–6 mm fraction. A large fraction of small aggregates are not desired due to reasons stated above, whereas a large fraction of aggregates >5–8 mm is not wanted due to risk of rapid drying and delayed emergence. Small seeded crops are normally more sensitive to seedbed structure and may require a finer and more homogeneous structure (Braunack and Dexter, 1989). Much less experimental work has been done on characterizing the optimal soil structure below the seedbed. However, results by e.g. Misra et al. (1986) support the perception that a crumb structure is desirable throughout the arable layer. Soil friability is not just relevant in conventional tilled systems—it is also of crucial importance in relation to successful seeding and crop establishment under no-till farming as highlighted by Macks et al. (1996). To sum up, soil friability concerns: 1. the strength of different sizes of unconfined soil and 2. the resulting fragment size distribution after applying a stress.

3. Assessment of soil friability

Soil friability has been assessed using qualitative field methods as well as quantitative field and laboratory methods at different scales of observation (Fig. 1). They measure different aspects of friability and have been used for different purposes. The qualitative field methods are broadly used by scientists, advisors and farmers, whereas the quantitative laboratory methods demand specialized skills and more or less sophisticated equipment. Most methods address only one aspect of soil friability, i.e. either the strength of unconfined soil or the