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Land management effects on the near-surface physical quality of a clay loam soil

W.D. Reynolds *, C.F. Drury, X.M. Yang, C.A. Fox, C.S. Tan, T.Q. Zhang

Greenhouse and Processing Crops Research Centre, Agriculture and Agri-Food Canada, 2585 County Road 20, Harrow, Ontario, Canada N0R 1G0

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Abstract

Although agricultural land management is known to affect near-surface soil physical quality (SPQ), the characteristics of these affects are poorly understood, and diagnostic SPQ indicators are not well-developed. The objective of this study was to measure a suite of potential SPQ indicators using intact soil cores and grab samples collected from the 0–10 cm depth of a clay loam soil with the treatments: (i) virgin soil (VS); (ii) long-term continuous bluegrass sod (BG); (iii) long-term maize (*Zea mays L.*)—soybean (*Glycine max* (L.) *Merr.*) rotation under no-tillage (NT); (iv) long-term maize–soybean rotation under mouldboard plough tillage (MP); (v) short-term (1–4 years) NT after long-term MP; (vi) short-term MP after long-term BG; (vii) short-term MP after long-term NT. Organic carbon content, dry bulk density, air capacity, relative water capacity and saturated hydraulic conductivity appeared to be useful SPQ indicators because they were sensitive to land management, and proposed optimum or critical values are available in the literature. Soil macroporosity was also sensitive to land management, but optimum or critical values for this parameter are not yet established. Soil matrix porosity and plant-available water capacity did not respond substantially or consistently to changes in land management, and were thus not useful as SPQ indicators in this study. Converting long-term BG to MP caused overall SPQ to decline to levels similar to long-term MP within 3–4 years. Converting long-term NT to MP or vice versa caused only minor changes in overall SPQ. With respect to the measured SPQ indicators and their optimum or critical values, both VS and BG produced ‘‘good’’ overall SPQ in the near-surface soil, while long-term maize–soybean rotation under NT and MP produced equally ‘‘poor’’ SPQ.

Keywords: Soil quality indicators; Clay loam soil; No-tillage; Mouldboard plough tillage; Bluegrass sod; Virgin soil; Organic carbon; Bulk density; Porosity; Air capacity; Plant-available water capacity; Hydraulic conductivity

1. Introduction

Soil quality may be defined as the ‘‘capacity of the soil to function within ecosystem and land-use boundaries to sustain biological productivity, maintain environmental quality, and promote plant and animal health’’ (Doran et al., 1996). An agricultural soil with good ‘‘quality’’ thus possesses all of the physical, chemical and biological attributes necessary to promote and sustain good agricultural productivity with negligible environmental degradation. A soil with poor quality, on the other hand, may not possess some or all of the attributes required for good agricultural production, or it may be prone to environmental degradation through wind/water erosion and leaching of agrochemicals, nutrients and pathogens into surface and ground water resources.

Due to the extreme complexity of the soil environment, agricultural soil quality is often segmented into

* Corresponding author. Tel.: +1 519 738 1265; fax: +1 519 738 2929.
E-mail address: reynoldsd@agr.gc.ca (W.D. Reynolds).

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''soil physical quality'', ''soil chemical quality'' and ''soil biological quality'' (e.g. Dexter, 2004a), although it is generally recognized that these components interact and are thus not truly separable. Soil physical quality refers primarily to the soil's strength and fluid transmission and storage characteristics in the crop root zone; which in turn result from soil physical properties (e.g. texture, structure, hydrology), climate, management practices (e.g. tillage, trafficking), crop types, and various soil-based chemical and biological processes (e.g. oxidation–reduction, mineralization, faunal activity). An agricultural soil with ''good physical quality'' is one that is strong enough to maintain good structure and hold field crops upright, but also weak enough to allow optimal proliferation of crop roots, soil flora, and soil fauna. Soil with good physical quality also has the ability to store and transmit water, air, nutrients and agrochemicals in ways which promote both maximum crop performance and minimum environmental degradation (Topp et al., 1997).

Soil physical quality is relevant and important for the entire crop rooting zone, which is approximately the top 1 m of the soil profile. However, the top 10 cm of soil is particularly important because it controls many critical agronomic and environmental processes, such as seed germination and early growth, aggregation, tillage impacts, erosion, surface crusting, aeration, infiltration, and runoff. In addition, many studies have found that the majority of soil physical quality responses to livestock treading, cropping and tillage occur in the top 5–15 cm of the soil profile (e.g. Drewry, 2006). For example, Singleton et al. (2000) showed that the deleterious effects of dairy cattle treading on the soil physical properties of pasture occurred primarily in the top 10 cm, regardless of soil type; and data in Drewry et al. (2001, 2004) and Drewry and Paton (2005) largely confirm this for dairy pasture on a humid silty clay loam soil. Carter (1988, 1990) also found changes in soil physical quality to occur primarily in the top 10 cm for row-crop spring cereals produced on a humid, fine sandy loam under mouldboard plough tillage and no-tillage. Hence, this study will focus on the physical quality of the top 10 cm of the soil profile.

A coherent and formalized set of soil physical quality indicators have not yet been developed, despite extensive efforts over the last couple of decades (Arshad and Martin, 2002). In addition, optimum/critical values or ranges for soil physical quality indicators are still largely unknown (e.g. Arshad and Martin, 2002), although various ''guidelines'' have been proposed for agricultural and non-agricultural soils (e.g. Hall et al., 1977; Greenland, 1981; Carter, 1990; Craul, 1999; Reynolds et al., 2002; Drewry and Paton, 2005). Nevertheless, it is becoming increasingly clear that organic carbon content, bulk density, permeability, and various forms of porosity, aeration and water retention will form key components of any integrative parameter or suite of parameters indicating soil physical quality. For example, Shukla et al. (2006) recently identified organic carbon content as the single most important parameter indicating the degree of soil aeration; and Dexter (2004b) found the slope of the soil water desorption curve at the inflection point to be a plausible indicator of soil structural quality. In addition, work by Hall et al. (1977), Greenland (1981), Carter (1990), de Witt and McQueen (1992), Reynolds et al. (2002), Drewry and Paton (2005) and others suggests that density, hydraulic conductivity and various air and water capacity relationships are potentially useful indicators of soil strength, soil water transmission, and soil air–water storage, respectively.

Studies aimed at defining and measuring soil physical quality should make use of soils under consistent, long-term land management (e.g. annual mouldboard plough cropping, continuous pasture, etc.) in order to ensure that quasi-stable end points or ''quasi-steady states'' in soil quality have been reached (Arshad and Martin, 2002; McQueen and Shepherd, 2002; Reynolds et al., 2002). It is also instructive, however, to investigate how soil physical quality parameters respond to sudden changes in land management, as this may shed light on the rate and mechanism by which the physical quality of a soil ''migrates'' from one steady state to another (Arshad and Martin, 2002; McQueen and Shepherd, 2002).

The objectives of this study were consequently to: (i) measure selected soil physical quality parameters in the near-surface (top 10 cm) of an annually cropped clay loam soil under long-term bluegrass sod, long-term mouldboard plough tillage, and long-term no-tillage; (ii) track the annual changes in the physical quality of this soil after converting long-term no-tillage to mouldboard plough tillage, long-term mouldboard plough tillage to no-tillage, and long-term bluegrass sod to mouldboard plough tillage; (iii) compare the measured parameter values to ''ideal/optimal/critical'' levels proposed in the literature, and to ''benchmark'' levels obtained for the soil under a ''native'' or ''virgin'' condition. Including virgin soil measurements provides an indication of the level of physical quality the soil attains through natural (non-anthropogenic) processes.