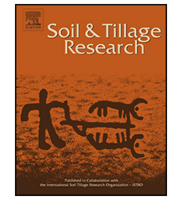
Soil & Tillage Research 151 (2015) 28–38

Contents lists available at ScienceDirect

Soil & Tillage Research

journal homepage: www.elsevier.com/locate/still




# Long-term agricultural management effects on surface roughness and consolidation of soils

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ARTICLE INFO

*Article history:*
Received 30 July 2014
Received in revised form 2 January 2015
Accepted 3 January 2015

*Keywords:*
Tillage effects on soil
Surface roughness change
Soil settlement
Soil consolidation

ABSTRACT

Soil surface characteristics affect soil–water interactions and are in turn influenced by a variety of soil properties. Likewise, the state and temporal change of soil surface roughness are major drivers for the interaction between soil and water.

The use of different tillage tools such as plough or chisel directly affects soil roughness parameters. Moreover, soil roughness and soil consolidation after management may also be affected indirectly through the effect of different management practices on soil properties.

This study examines the effects of two different long-term soil management experiments on soil roughness and the process of soil consolidation. At site Fuchsenbigl (FB), conventional tillage has been compared to reduced tillage since 1988. At site Ritzlhof (RH), three different methods of fertilization (green waste, mineral fertiliser, no fertiliser application) have been tested since 1991. We assumed that the different management practices had influenced soil properties – most likely organic carbon content – affecting soil roughness and soil consolidation.

The photogrammetric method was applied to test these assumptions, and various soil surface roughness indices (random roughness, orientated roughness, limiting slope, limiting distance, tortuosity) successfully identified different initial roughness values.

The limiting elevation difference index (Linden and van Doren, 1986) revealed significant differences between the sites FB 2012 (17 mm) and RH 2012 (28 mm) and between different years RH 2013 (22 mm) after chiselling. We attributed the site distinction to the different soil textures and the temporal differences to the different water contents at time of management.

The decay of roughness for all sites and treatments ($n = 276$) parameterized by the RR Index followed the equation $RR = 94.6\ e^{-0.001}$.

We were also able to distinguish significant consolidation effects of different long-term treatments with respect to tillage intensity at site FB. The maximum consolidation for reduced tillage was 13.8 mm compared to 16.8 mm for conventional treatment. In contrast, no effects of different fertiliser application at site RH were observed. For all sites and treatments ($n = 35$), soil consolidation (C in mm) due to precipitation (P in mm) followed the equation $C = 4.23 \times \ln(1 + P)$ with an $r^2$ of 0.71.



## 1. Introduction

Soil surface roughness affects the interaction between soil and water in various ways. It controls the amount of water directly stored at the surface (Guzha, 2004; Linden et al., 1988) and affects infiltration characteristics (Dimanche and Hoogmoed, 2002). Soil surface roughness also strongly influences the spatial distribution (Helming et al., 1998) and the time of runoff generation (Darboux et al., 2004). Because soil surface roughness is a determining parameter of these processes, methods to index soil surface characteristics have been developed over the last decades. First experiments were carried out on linear segments, where soil height was measured via relief meters (Allmaras et al., 1966; Zobeck and Onstad, 1987). This method was later modified to increase precision (Currence and Lovely, 1971). The use of photogrammetric methods and laser technology enabled better spatial resolution and sped up computation time (Borselli and Torri, 2010; Grims et al., 2014; Hansen et al., 1999; Lehrsch et al.,

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http://dx.doi.org/10.1016/j.still.2015.01.017

1988). In a comparative study, laser technology and photogrammetry were identified as currently being the most suitable to assess soil surface roughness (Jester and Klik, 2005). Photogrammetric methods have been in use for almost two decades to detect soil surface roughness (Warner, 1995). The main advantage of photogrammetric methods compared to others is that they are easy to handle in the field, the observed area is not influenced by the measuring process, a permanent photogrammetric record is available (Warner, 1995), and high resolution of soil surfaces (down to millimetres for all three dimensions) can be obtained (Marzahn et al., 2012; Mirzaei et al., 2012; Moritani et al., 2011).

Numerous indices have been proposed to parameterize soil surface roughness. The most commonly used is probably the random roughness index (rrAR) described by Allmaras et al. (1966) and Zobeck and Onstad (1987). It is calculated as the standard deviation of the logarithmic height readings in inches or centimetres. rrAR or derivations of it are implemented in a variety of soil erosion models to account for the effect of surface water storage or infiltration characteristics on the generation of surface runoff and soil erosion. In the Revised Universal Soil Loss Equation (RUSLE) provided by Renard et al. (1997) for instance, a negative exponential correlation between soil surface roughness and soil erosion is used to account for the effect of temporal decrease of surface roughness for different management practices.

Currence and Lovely (1971) described another set of different calculation methods for roughness estimation, i.e. random roughness (RC), orientated roughness ($RC_X$), orientated roughness ($RC_Y$) to describe physical processes affected by tillage. In general the proposed procedure is quite similar to that of Allmaras et al. (1966) with the difference that they did not convert height readings into their natural logarithms and did not remove any data for processing They also divided roughness into overall roughness (RC) and oriented roughness ($RC_X$, $RC_Y$) to account for tillage direction effects. The chain method provided by Saleh (1993) is based on the principle that a chain of a given length was placed across a soil surface segment. The horizontal distance covered by the chain decreases as surface roughness increases (Gilley and Kottwitz, 1995; Saleh, 1993). An area approach of the chain method named tortuosity index (TB) is used in several studies (Helming, 1992; Kamphorst et al., 2000; Mirzaei et al., 2012; Taconet and Ciarletti, 2007).

Linden and van Doren (1986) provided two further indices that are based on spatial variability: limiting slope (LS) and limiting elevation difference (LD). These indices are based on the principle of semivariogram analysis. LS and LD have both been tested in work of Borselli and Torri (2010),Hansen et al. (1999) and Mirzaei et al. (2012).

A variety of additional indices to describe soil surface roughness exists which have been already tested with more or less success. Lersch et al. (1988) provide a compilation of an additional set of statistically based roughness indices such as maximum peak height, maximum depression depth, peak frequency and micro relief indices.

We chose to use rrAR, RC, $RC_X$, $RC_Y$, LD, LS and TB for our study (Table 2). All indices based on random roughness considerations were taken into account because this index is the only one which has been used broadly in soil erosion models (for instance RUSLE, EUROSEM and WEPP). Thus they seem to be of special importance for practical implementation of roughness into environmental modelling. The importance of roughness for soil erosion can be underlined by the fact that according to the assumptions of the RUSLE model (Renard et al., 1997) a rrAA index of 10 (after seedbed preparation, 9% slope) changes mean average soil erosion by a factor of 1.5 as compared to a rrAA index of 50 (after ploughing) for typical climatic, crop cycles and soil conditions in Austria. LD and LS were chosen because of their proven ability to describe temporal soil roughness decay (Hansen et al., 1999).

The process of consolidation starts after the initial soil surface roughness is established. It is the response of a soil to an applied stress – either mechanical by soil weight or hydraulic by rainfall (Alaoui et al., 2011; Keller et al., 2013). Soil consolidation affects the nutrient uptake, nutrient transformation (Lipiec and Stępniewski, 1995), aeration (Hamza and Anderson, 2005), soil microbiology (Weisskopf et al., 2010) and hydraulic properties of soils (Ahuja et al., 1998; Alaoui et al., 2011; Strudely et al., 2008). Soil consolidation influenced by precipitation depends on the initial water content at tillage time (Allmaras et al., 1966; Arvidsson and Bölenius, 2006) and on soil texture (Peng et al., 2006).

Soil consolidation and the dynamics of changes have been traditionally measured by sampling undistributed soil cores (Hartmann et al., 2012) with subsequent lab analysis. Unfortunately, bulk density from core sampling directly after field management operations is often unreliable. This is because large voids are destroyed during sampling, influencing the results (Arvidsson and Bölenius, 2006; Dexter 1997). Therefore Chang et al. (2007) suggest an alternative method for studying temporal changes in soil constituents. It involves elevation-based sampling to obtain reliable results on soil consolidation, swelling and shrinkage.

Only few measurements are available of soil surface roughness in high temporal resolution and of soil consolidation under natural conditions (Arvidsson and Bölenius, 2006; García Moreno et al., 2011; Haubrock et al., 2009). We expected effects of different management practices on these soil surface characteristics because various authors report impacts of different tillage or fertilisation practices on soil physical parameters and soil organic carbon content. Rasmussen (1999) and Tebrügge and Düring (1999) reviewed that soil bulk density increases under reduced tillage compared to conventional tillage. They reported changes in soil macropore distribution and therefore in soil hydraulic conductivity. Arshad et al. (1999) and Jiao et al. (2006) showed that no-till management improves water-stable aggregation of soil clods. Spiegel et al. (2007) reported that long-term tillage management affects soil organic carbon, soil nitrogen and pH. Furthermore, soil physical parameters are distinctly influenced by fertiliser application. Rasool et al. (2008) studied the effects of different forms and amounts of fertilisers on bulk density, organic carbon content, structural stability of soil aggregates and water holding capacity. Jung et al. (2011) identified that aggregate stability is significantly lower at high versus low application of nitrogen fertiliser. Jiao et al. (2006) emphasised that composted manure produces more water-stable aggregates than inorganic fertilisers. Therefore soil roughness and/or consolidation parameters might be used as indicators for soil structural changes and to identify changes in soil quality due to differences in management.

The present study evaluates the effect of different long-term management methods on (i) initial soil roughness directly after tillage (ii) soil roughness decay by natural precipitation, and (iii) natural soil consolidation. The present study evaluates the effect of different long-term management methods on (i) initial soil roughness directly after tillage (ii) soil roughness decay by natural precipitation, and (iii) natural soil consolidation. We tested these effects based on two long-term field experiments. One of these experiments deals with the application of different types and amounts of fertilisers, the other with the effects of different tillage practices. To assess soil roughness and soil consolidation and to derive various soil roughness indices, we applied a photogrammetrically based method (Grims et al., 2014), which was modified to fit the requirements for estimating soil consolidation.