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Transformation of ex-arable land to permanent grassland promotes pore rigidity and mechanical soil resilience

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ABSTRACT

The conversion of degraded arable land to permanent grassland is widely presumed to be amendatory and is therefore proposed as a climate-smart agriculture strategy, which may rapidly restore soil quality. However, the rate and extent of soil repair will largely depend, on the management practices, deployed in the permanent grassland. In this study, our objective was to assess the effects of no-till and no-renovation management, on aggregation, internal soil strength parameters and pore system dynamics of permanent grassland, established from degraded arable land. Also, we analysed the time dependence of these changes on the some functions of the soil. Undisturbed samples were collected at 3 depths: 0–10 cm, 10–25 cm and 25–40 cm, from permanent grassland, aged 1, 8 and 19-years, and were used to determine water retention and saturated hydraulic conductivity for each sward age. Moreover, compression properties and shear stress parameters at these depths and sward-ages were determined. The results indicated remarkable improvement in pore structure in relation to the age of each sward, which resulted in improved water retention, air and water fluxes with the age of the grassland. The shear parameters and precompression stress data showed differences in the structural recovery timeline at the various depths, highlighting the difference in ecological engineering processes as a function of the time since the grassland was established and the depth considered. Our results indicate that permanent grassland management will contribute to a substantial recovery of pore functions, coinciding with enhanced pore rigidity and increased soil strength which may also influence sequestration potential in the grassland.

1. Introduction

Grasslands and integrated grassland systems makes up about 70 percent of the world's agricultural area, and support the livelihoods of almost one billion people (FAO, 2009; Conant, 2010). They are very critical to several ecological processes in the soil, and evapotranspiration (ET) flux that accounts for approximately two thirds of terrestrial precipitation worldwide (Mix et al., 2013). They are also critical to the evolution of the Earth's climate system (Erfanzadeh et al., 2014). Moreover, grasslands are major reservoir of terrestrial carbon (Rees et al., 2005; Fontaine et al., 2007); with about 44% (591.6 Gt) of the world's total soil carbon which is stored in them (Post and Kwon, 2000; Lal, 2004; Conant, 2010). The reservoir can be rapidly depleted or increased, depending on the effect of management effects on soil quality (Lal, 2004; Six et al., 2004; Fornara et al., 2011). In addition, grasslands host high biodiversity and provide vital environmental services for the society (Bedoin and Kristensen, 2013). Improved management of grasslands is therefore essential to sustainable livestock production, ecosystem balance and carbon sequestration (Conant, 2010; Fornara et al., 2011; Necpálová et al., 2013).

The sustainability of grassland management system, like any other agricultural systems, can be assessed from its preservation and improvement of soil physical quality over time. For instance, the maintenance of soil organic matter (SOM) is important for continuous forage production (Conant et al., 2001; Lemaire et al., 2005; Loucougaray et al., 2015), while improved aggregate characteristics, directly influences the amount of carbon sequestered (Mordhorst et al., 2014) and redox process (Zausig et al., 1993) in the soil. It is therefore important to investigate in more detail, the impact of management system on soil quality indicators in grassland, particularly in erstwhile arable land that was mainly converted to permanent grassland, as a means of restoring degraded soil quality.

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When degraded arable land is converted to permanent grassland, three major issues are of critical research interest, in relation to soil quality: (i) structural recovery in the soil matrix, (ii) the time and depth dependence of the recovery, and (iii) the effects of trampling and driving due to grazing or mowing on the soil structure recovery. The conversion of arable land to permanent grassland could cause a complete suppression or pronounced changes in pore functions of the soil, depending on the management intensities (Guo and Gifford, 2002; Soussana et al., 2004; Linsler et al., 2013). Furthermore, it is argued that the disruption of soil structure during reseeding (renovation) for improved fodder production may negatively impact on soil moisture capacity, aggregation, temperature regime and accelerate the mineralization processes in the soil (Horn 1990; Soussana et al., 2004; Lal, 2004; Linsler et al., 2013). Therefore, no-till management is often recommended as best protective activity in amendatory grasslands (Lal, 2003). For instance, Mordhorst et al. (2014) proofed that the greater amount of carbon (nearly double) is stored in the aggregates of soil managed for a long time under no-till (NT) compared to aggregates from soil under the convention tillage (CT) system (i.e. ploughing and harrowing). Furthermore, the aggregates from these NT sites were much stronger than those from the CT sites, which coincide with a more effective sequestration. Thus, from the ecological point of view, it is very important to optimize the rigidity of soil structure and improve the exchange surfaces within the aggregates. Consequently, it will be helpful to determine the time scale to achieve structural rigidity in erstwhile arable land, which has been converted to permanent grassland for the purpose of restoring the soil functions.

We hypothesized that (i) the conversion of arable land to permanent grassland for amendatory purposes, promotes a more rigid and less entropic soil system, which as an additional effect, will optimize the soil physical and physicochemical properties and functions; and (ii) structural recovery in the amendatory grassland is time and depth dependent. The objective of this study was therefore to evaluate the impact of no-till and no-renovation management, on some mechanical and hydraulic properties of eutric luvisols used for several years for arable farming and later converted to permanent grassland. We also seek to assess the effect of the soil depth and the time since the permanent grassland was established, on changes in the soil pore functions. Soil water retention curves, hydraulic conductivities, precompression stresses, and shear strength parameters at 1-, 8- and 19-years old swards were compared to examine improvement of soil physical and hydraulic properties and also to assess the changes in structural stability.

2. Material and methods

2.1. Experimental site

The study was carried out at the Experimental Farm of the Faculty of Agriculture, Christian Albrechts University, Kiel, located in Lindhof (54°27‘N, 9°57‘E; 15 m a.s.l.). The soil types within the experimental farm vary over short distances between Cambisols, Eutric Luvisols, Stagnosols and Anthrosols. The climate of the study site is oceanic with moderately cool summers and comparatively warm winters. The long term mean annual temperature is 8.7 °C and the mean annual precipitation 785 mm (Schmeer et al., 2009; Linsler et al., 2015).

The experimental farm has been used for the production of potatoes (*Solanum tuberosum* L.), oats (*Avena sativa* L.) and winter wheat (*Triticumaestivum* L.) under intensive tillage management (i.e. mechanical ploughing and harrowing) and inorganic fertilisation for several years, in well-planned rotation. In 1993, the farming practice was changed to organic management, in accordance with the guidelines of the German organic growers association (Bioland, 2012).

In 1994, 2004 and 2012, some parts of the arable field were converted to permanent grassland (while the other part remained as arable land), as part of large experimental project, which was investigating the effects of grassland renovation and conversion of arable land into grassland, on nitrogen fluxes and carbon storage (Linsler et al., 2015). The experimental plots, measuring 6 m x 18 m with four replicates, were arranged in a randomized block design. The grassland plots were seeded with grass–clover mixture that contains 63% perennial ryegrass (*Lolium perenne* L.), 16% Timothy grass (*Phleum pratense* L.), 9% smooth meadow-grass (*Poa pratensis* L.), and 12% white clover (*Trifolium repens* L.). For the renovation treatment, some plots which were converted to grassland since 1994 were tilled with a mouldboard plough to a depth of 25 cm in October 2005 and winter wheat (*Triticum aestivum* L. variety Bussard) was sown. After the wheat harvest, the plots were tilled again in September 2006 to incorporate straw and stubble. Soon afterwards, 30 kg ha^{-1} of grass clover mixture was sown (Linsler et al., 2014). Between 1994 and 2005, the grassland was normally cut (manually) 1–2 times per annum for silage production and grazed 3–4 times by cattle each year. Since 2005 the grassland has been generally cut four times each year for forage production (Schmeer et al., 2009).

For this study, we sampled from the permanent grassland plots with no fertilization (no slurry treatment) and under a no-till and no-renovation management, established in 1994, 2004 and 2012. Thus, the sward ages were: 1, 8 and 19-years at the time of sampling. The dominant soil type in these plots is Eutric Luvisol derived from glacial till. The soil texture in the Ap/E horizons (0–40 cm) is sandy loam to loamy sand, with the sand, silt, and clay content averaging at 67 ± 1.3%, 23 ± 0.7%, and 10 ± 0.8%, respectively, and a pH value of 5.74 ± 0.05 (Ziogas, 1995).

2.2. Sampling procedure

Two sets of soil samples, collected in each plot (studied sward age) at 3 the depths/layers: T: topsoil (0–5 cm), Ss: subsurface (10–15 cm) and D: deep (20–25 cm) were used in this study. The first set of samples, consisted of 40 undisturbed cores, (100 cm^3; 4 cm height, 5.65 cm diameter) for the determination of water retention, saturated hydraulic conductivity (ks), air conductivity and shrinkage behaviour. The second set consisted of 15 undisturbed cores (236 cm^3; 3 cm height, 10 cm diameter) for the determination of precompression stress and the shear strength parameters.

2.3. Water retention

Water retention properties for each sampled layer in the different sward ages, was determined with 15 undisturbed soil cores. These samples were first trimmed in the laboratory to the exact sizes of their cylinder, slowly saturated by capillary rise with de-aired water. After saturation, the soil samples were gradually dewatered to the matric potential of −6, −15, −30, −50 kPa on ceramic plates, and the samples were weighed at each drainage step. The dry bulk density of each sample was determined by drying the cores in the oven at 105 °C for 16 h, after the last drainage step, and used to calculate the volumetric water content. The gravimetric water content at −1500 kPa for each sampled layer was determined from disturbed and thoroughly moistened samples, packed in very small rings (20 samples per treatment). The samples were pneumatically drained on ceramic plates, placed within a pressure chamber for about 21 days and later oven dried at 105 °C for 16 h. The volumetric water content at 0 kPa was taken as the total porosity (TP). Air capacity (AC) (Ψm0 and Ψm − 6 kPa), and the available