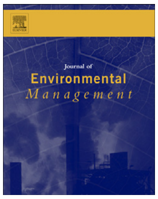
Journal of Environmental Management 181 (2016) 54–63

Contents lists available at ScienceDirect

Journal of Environmental Management

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



Research article

Environmental impacts of different crop rotations in terms of soil compaction

Philipp Götze [a, *], Jan Rücknagel [a], Anna Jacobs [b], Bernward Märländer [b], Heinz-Josef Koch [b], Olaf Christen [a]

[a] Department of Agronomy and Organic Farming, Martin Luther University Halle-Wittenberg, Betty-Heimann-Str. 5, 06120, Halle/Saale, Germany
[b] Institute of Sugar Beet Research, Holtenser Landstrasse 77, 37079, Göttingen, Germany

ARTICLE INFO

Article history:
Received 31 August 2015
Received in revised form
16 May 2016
Accepted 18 May 2016

Keywords:
Sugar beet
Silage maize
Air capacity
Saturated hydraulic conductivity
REPRO

ABSTRACT

Avoiding soil compaction caused by agricultural management is a key aim of sustainable land management, and the soil compaction risk should be considered when assessing the environmental impacts of land use systems. Therefore this project compares different crop rotations in terms of soil structure and the soil compaction risk. It is based on a field trial in Germany, in which the crop rotations (i) silage maize (SM) monoculture, (ii) catch crop mustard (Mu)_sugar beet (SB)-winter wheat (WW)-WW, (iii) Mu_SM-WW-WW and (iv) SB-WW-Mu_SM are established since 2010. Based on the cultivation dates, the operation specific soil compaction risks and the soil compaction risk of the entire crop rotations are modelled at two soil depths (20 and 35 cm). To this end, based on assumptions of the equipment currently used in practice by a model farm, two scenarios are modelled (100 and 50% hopper load for SB and WW harvest). In addition, after one complete rotation, in 2013 and in 2014, the physical soil parameters saturated hydraulic conductivity (k_S) and air capacity (AC) were determined at soil depths 2–8, 12–18, 22–28 and 32–38 cm in order to quantify the soil structure. At both soil depths, the modelled soil compaction risks for the crop rotations including SB (Mu_SB-WW-WW, SB-WW-Mu_SM) are higher (20 cm: medium to very high risks; 35 cm: no to medium risks) than for those without SB (SM monoculture, Mu_SM-WW-WW; 20 cm: medium risks; 35 cm: no to low risks). This increased soil compaction risk is largely influenced by the SB harvest in years where soil water content is high. Halving the hopper load and adjusting the tyre inflation pressure reduces the soil compaction risk for the crop rotation as a whole. Under these conditions, there are no to low soil compaction risks for all variants in the subsoil (soil depth 35 cm). Soil structure is mainly influenced in the topsoil (2–8 cm) related to the cultivation of Mu as a catch crop and WW as a preceding crop. Concerning k_S, Mu_SB-WW-WW (240 cm d^{-1}) and Mu_SM-WW-WW (196 cm d^{-1}) displayed significantly higher values than the SM monoculture (67 cm d^{-1}), indicating better structural stability and infiltration capacity. At other soil depths, and for the parameter AC, there are no systematic differences in soil structure between the variants. Under the circumstances described, all crop rotations investigated are not associated with environmental impacts caused by soil compaction.

1. Introduction

Indicator based assessments of the environmental impact of land use systems often do not include their influence on soil structure and the soil compaction risk (Castoldi and Bechini, 2010; Gaudino et al., 2014; Paracchini et al., 2015). However, soil structure is an important criterion of soil fertility (Mueller et al., 2010) since it determines the water and air balance as well as the rootability (Hartge, 1994) and the habitat quality for soil organisms (Birkás et al., 2004). Accordingly, soil compaction has a negative impact on the essential soil functions, resulting in increased environmental impacts (Nawaz et al., 2013). Preserving a functional soil structure and avoiding soil compaction are therefore important aspects of sustainable agriculture. Preventive measures, from using adapted

---

* Corresponding author.
E-mail addresses: goetze@ifz-goettingen.de, philipp.goetze@landw.uni-halle.de (P. Götze), jan.ruecknagel@landw.uni-halle.de (J. Rücknagel), jacobs@ifz-goettingen.de (A. Jacobs), maerlaender@ifz-goettingen.de (B. Märländer), koch@ifz-goettingen.de (H.-J. Koch), olaf.christen@landw.uni-halle.de (O. Christen).

http://dx.doi.org/10.1016/j.jenvman.2016.05.048

chassis and tyres which protect the soil right up to Controlled Traffic Farming (CTF), are preferable since they are less expensive than taking subsequent remedial action (Chamen et al., 2015). Another method of preventive soil protection is to consider the effect of crop species on the formation of soil structure – as well as the soil compaction risk associated with cultivating these species – when planning the crop rotation.

Cultivating a crop can influence the soil structure by a number of factors. Aspects of root morphology and physiology are often discussed in this context, as well as the impact of harvest residues (Bronick and Lal, 2005; Blanco-Canqui and Lal, 2009). However, the effect of the crop or of the crop rotation on soil structure is often masked by the tillage method (Malhi et al., 2008) or by different levels of mechanical stress when driving over the soil with agricultural machinery (Boizard et al., 2002; Capowiez et al., 2009). A positive influence on soil structure is attributed to legumes and perennial forage crops. Specifically, cultivating them can result in increased macroporosity and hydraulic conductivity (McCallum et al., 2004) as well as aggregate stability (Reid and Goss, 1981), while dry bulk density and penetration resistance can decrease (Chan and Heenan, 1996).

Cultivating crops for bioenergy use aims to reduce environmental impacts, especially greenhouse gas emissions. Therefore crop rotations including crops with the lowest energetic input-output ratio are advantageous. In terms of biogas production under the conditions in Central Europe, silage maize (SM, *Zea mays* L.) and sugar beet (SB, *Beta vulgaris* L.) are suitable due to their high methane yields (Amon et al., 2007; Weiland, 2010; Brauer-Siebrecht et al., 2016). However, aspects concerning the impact on soil structure should be considered for the cultivation of crops for bioenergy use and only few results have been published on the impact of SB and SM on soil structure (Boizard et al., 2002; Deumelandt et al., 2010; Głąb et al., 2013; Jacobs et al., 2014). Therefore, this paper aims to identify the impacts of cultivating SB and SM in crop rotations with winter wheat (WW, *Triticum aestivum* L.) as well as of SM monoculture on soil structure. Due to the numerous factors which influence soil structure and the way they interact, it is expedient to integrate several methodological approaches to compare the soil structure related to different cultivation practices. To this end, physical soil parameters are recorded in a crop rotation experiment, in order to, first of all, present the crop-specific impact on soil structure under field trial conditions. Furthermore, model calculations are used to derive the soil compaction risk associated with common cultivation methods used for the entire crop rotation. This is based on a model farm which is assumed to use modern, standard equipment and refers to the operations and respective dates performed during the field trial. The validity of the model used is tested by field investigations into physical soil parameters. Finally, the results of both methods are used to assess the environmental impacts by soil compaction for different crop rotations.

2. Materials and methods

2.1. Field site and experimental design

A crop rotation field trial set up in 2010 in Aiterhofen (Germany, Lower Bavaria, 48°85′ N; 12°63′ E) forms the basis of these investigations. In this field trial, soil samples were taken in order to identify physical soil parameters and the soil structure. The field trial's cultivation dates (driving dates) as well as site information serve to model the soil compaction risk.

The soil type is classified as a Luvisol (FAO, 2014), and the soil texture at a depth of 0–45 cm is that of a silt loam (205 g kg^{-1} clay, 128 g kg^{-1} sand). Long-term (1981–2010) average annual precipitation is 757 mm, and the mean annual temperature 8.6 °C (Straubing station, DWD, 2014). The field trial tests four crop rotations, containing SB, SM and WW as well as mustard as a catch crop (Mu, *Sinapis alba* L.) (Table 1). The field trial has a block design with four replications, with each crop rotation field being sown every year on a separate plot. Every replication comprises 10 plots, each of them 420 m^2 in size.

Primary tillage is performed as conservation tillage in the autumn, using a cultivator at a soil depth of 18 cm (working width 3 m). For SM, seedbed preparation is performed using a rotary harrow (working width 3 m, working depth 10 cm) and for SB using a seedbed cultivator (working width 5.6 m, working depth ≤5 cm). For WW, seedbed preparation is performed using a rotary harrow (working width 3 m, working depth ≤10 cm) in combination with the seeder. For the spring crops SB and SM which follow WW, the catch crop Mu is sown in combination with primary tillage in August after WW harvest. Additionally, nitrogen fertilization is carried out using 40 kg N ha^{-1} UAN (solution of urea and ammonium nitrate). Nitrogen fertilization for the main crops is performed using UAN depending on the amount identified as optimal for each particular year. Work performed at the field trial uses machinery typically employed in practice; special trial equipment is only used for sowing SB (three-row plot drill). SB are harvested using a six-row self-propelled SB harvester. The WW harvest is performed using a self-propelled combine harvester. A self-propelled forage harvester is used to harvest SM, with the harvested crop transferred onto a transport vehicle during operation.

2.2. Investigations into soil structure at the field trial Aiterhofen

After having completed the entire rotation on each plot, in May 2013, samples were taken from those plots with the first crop rotation field (Table 1) of all crop rotations. The sampling was repeated in 2014 for the same crop rotation fields which were than cultivated on different plots, except the SM monoculture. The Sampling was conducted after the emergence of SB and SM. Undisturbed soil core samples (250 cm^3, height 6 cm, n = 4 per plot and depth) from soil depths 2–8 cm, 12–18 cm, 22–28 cm and 32–38 cm were saturated and then adjusted to a matrix potential of −6 kPa in a sand box in order to determine air capacity (AC) (ISO 11274:1998). Subsequently, the same soil cores were used to determine saturated hydraulic conductivity (k_S) in a stationary system (percolation time 4 h) (ICS 13.080; 65.060.35).

Table 1
Schemata for the crop rotations per replication at field site Aiterhofen (SB – sugar beet; WW – winter wheat; SM – silage maize; Mu – mustard catch crop, Mi – millet).

Crop rotation		Year				
No.	Plot	2010	2011	2012	2013	2014
1	1.1	SM	SM/Mi[b]	SM	SM[a]	SM[a]
2	2.1	Mu_SB	WW-1	WW-2	Mu_SB[a]	WW-1
	2.2	WW-1	WW-2	Mu_SB	WW-1	WW-2
	2.3	WW-2	Mu_SB	WW-1	WW-2	Mu_SB[a]
3	3.1	Mu_SM	WW-1	WW-2	Mu_SM[a]	WW-1
	3.2	WW-1	WW-2	Mu_SM	WW-1	WW-2
	3.3	WW-2	Mu_SM	WW-1	WW-2	Mu_SM[a]
4	4.1	SB	WW-1	Mu_SM	SB[a]	WW-1
	4.2	WW-1	Mu_SM	SB	WW-1	Mu_SM
	4.3	Mu_SM	SB	WW-1	Mu_SM	SB[a]

[a] Plots with investigations into soil structure.
[b] Mi was cultivated because of regional quarantine regulations.