Forest Ecology and Management 380 (2016) 224–231

Contents lists available at ScienceDirect

Forest Ecology and Management

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

Soil aeration and soil water tension in skidding trails during three years after trafficking

Heinz-Christian Fründ *, Audrey Averdiek

University of Applied Sciences, Am Krümpel 31, D-49090 Osnabrück, Germany

ARTICLE INFO

Article history:
Received 27 June 2016
Received in revised form 6 September 2016
Accepted 7 September 2016

Keywords:
Soil compaction
Wheel track
Redox indication
CO_2-concentration
Soil moisture
Soil recovery

ABSTRACT

Parameters of soil aeration and of soil water tension were measured for three years in skid trails of a 34 year old beech forest from natural regeneration which received its first thinning. The investigation took place in the Solling (Germany, Lower Saxony) at 400 m a.s.l. where cambisols have developed from silty Pleistocene deposits on Triassic sandstone. During thinning skid trails were laid out with a harvester, followed by a forwarder. The following measurements were made (i) in the undisturbed soil, (ii) in the wheel track, (iii) in the middle line between the wheel tracks: Continuous monitoring of water tension in 6–10 cm soil depth and soil air CO_2-concentration in 6 cm soil depth. Iron rods in the soil (down to 27 cm) were taken as indicators for soil aeration (redox indication) and were exposed for four weeks in late summer every year.

Research questions were: How does the soil air CO_2-concentration and soil water tension change in time? How is soil air CO_2-concentration related to soil water tension and to soil temperature? What is the course of CO_2-concentration and soil water tension in the skid trail middle lane compared to undisturbed soil and wheel-track soil? Can iron rods reflect the soil aeration difference between trafficked and undisturbed soil?

CO_2 measurement, monitoring of soil water tension, and redox indication with iron rods showed that driving with harvester and forwarder not only affected the wheel tracks but also the unpassed middle lane of the skidding trails. Decrease of CO_2-concentration in the soil air indicated an initial regeneration of air diffusivity in the first 6 cm of the impacted soil within the first three years after trafficking. Iron rods had significantly different frequencies of reducing conditions in the order wheel tracks > middle lane between wheel tracks > undisturbed soil. Iron rods indicated no recovery of soil aeration in depth 12–24 cm during the three years of observation. The soil water tension reflected the transpirational water extraction by trees in the undisturbed soil in the course of the vegetation period (from spring to summer/autumn). In the skid trail the water tension indicated a more water filled porosity than in the undisturbed soil. The generally weaker water tension in the skid trails indicated, that also the middle lane between the wheel tracks was separated from the transpirational flow of soil water to the trees. CO_2-concentration in soil air at 6 cm depth in summer was more related to soil water tension than to soil temperature.

1. Introduction

Driving on forest soil bears a high risk of causing soil damage due to soil compaction and rutting (Greacen and Sands, 1980; Cambi et al., 2015). This has led to the enforcement of permanent skidding trails by certification agencies (FSC: Forest Stewardship Council, PEFC: Programme for the Endorsement of Forest Certification Schemes) and forest managers (in Germany e.g. MLR, 2003; Bayerische Staatsforsten, 2010). Furthermore threshold values of damage indicators were set up to trigger the cancellation of harvesting activity in case of unacceptable soil damage (Lüscher et al., 2010; AG Bodenschutz Niedersächsische Landesforsten, 2014; Kremer et al., 2012). In consequence a permanent grid of development lines is laid out comprising of a 4 m wide skidding trail every 20 m, where soil compaction is accepted as a compromise between economic demands and ecological conservation of soil function. Hence parts of ecological soil functions in 20% of the forest area may be sacrificed for economic benefits. Structural soil damage may result from compaction or kneading (rutting).

Abbreviations: a.s.l., above sea level; [CO2], CO_2-concentration in soil air; SWT, soil water tension; WFPS, water filled pore space.

* Corresponding author.
E-mail address: h-c.fruend@hs-osnabrueck.de (H.-C. Fründ).

http://dx.doi.org/10.1016/j.foreco.2016.09.008
0378-1127/© 2016 Published by Elsevier B.V.

While the lateral and vertical spread of compaction stress can be easily described according to Boussinesq theory (Hillel, 1998), the extension of kneading effects is less predictable. It is connected with the disruption of pore continuity blocking exchange processes in the soil. The total impact of machine trafficking on forest soils is determined by (i) the area which is impacted by driving, (ii) the depth of impact, (iii) the duration/irreversibility of the soil structural damage.

A lateral extension of soil compaction from the wheel track was observed frequently but not in any case (Labelle and Jaeger, 2011; Ampoorter et al., 2010). In particular the middle line between the wheel tracks may be impacted from skidded logs (Dickerson, 1976) but also indirectly from the disturbed wheel tracks (Ampoorter et al., 2010).

Compaction by vehicle driving in forest soil has been observed to range down to 40 cm depth (Riggert et al., 2016). Maximum compaction occurs in 10–30 cm depth (Labelle and Jaeger, 2011; Cambi et al., 2015). But Gaertig et al. (2002) point out, that aeration deficiency rather than compaction is decisive for the soil ecological impact, and this is driven by the gas diffusivity of the uppermost 5 cm of the soil profile.

Observations on the recovery time of compacted wheel tracks in forests range from 3 years (Bekele et al., 2007; Reisinger et al., 1992) to more than 10 years (Dickerson, 1976; Wilpert and Schäffer, 2006; Ebeling et al., 2016) and even more than 70 years (Webb et al., 1986). The wide range of recovery times is due to site specific differences in water regime, clay content and soil biological activity (Cambi et al., 2015; Ebeling et al., 2016).

We hypothesized:

After trafficking the CO_2-concentration in soil air ($[CO_2]$) in the upper soil (6 cm) is strongly increased in tracks but not in the middle lane.

$[CO_2]$ is related to water filled pore space (WFPS) and soil temperature.

After trafficking there are less macropores and thus more WFPS (measured as lower SWT) in the skid track than in the undisturbed soil.

The nearly unpassed middle lane of the skid trail has a dynamic of soil water tension (SWT) that is similar to the undisturbed soil.

Iron rods reflect the soil aeration difference between wheel tracks, middle lane and undisturbed soil.

2. Material and methods

2.1. Site and skid trails

The investigated site is a 34 year old beech forest from natural regeneration in the Solling. The Solling is a mountain range of Triassic sandstone situated in Lower Saxony, Germany. Elevation of the investigated site is 400 m a.s.l, the mean annual precipitation at a monitoring site on 500 m a.s.l. is 1000 mm. The soils are cambisols from silty Pleistocene deposits (clay 18.6 ± 2.9%, silt 66.5 ± 4.9%, sand 14.9 ± 2.7%, pH($CaCl_2$) = 3.8–4.2, C_{org}(0–5 cm) = 86 ± 21 g kg^{-1}) (Fründ et al., unpublished data). The site has a slope inclination (10%...19%) facing east. Upon first thinning of the site December 2012 to March 2013 skid trails were laid out with a Logset F5 harvester (13 tons, 700 mm tire width, 3.3 bar tire pressure, 2 passings) followed by a Ponsse Buffalo forwarder (18 tons + load, approx. 6–10 passings, 700 mm tire width, 4 bar tire pressure). During wheeling there was no frost and the soil water was at or above field capacity. Both machines used the same line. When machine working was finished, a 50 m line was designated in three skid trails as measurement plot.

The rut depth in the wheel tracks ranged from 5 to 15 cm. The ruts were lined by bulges reaching up to 7 cm height. Bulk density in 5–10 cm depth was 1.12 ± 0.16 g/cm^3 in the untrafficked soil, 1.22 ± 0.21 g/cm^3 in the wheel tracks, 1.19 ± 0.19 g/cm^3 in the middle lane between wheel tracks. The percentage of C_{org} in the skid trail soil (0–5 cm) was reduced to 53 ± 24 g kg^{-1} in the wheel track and to 69 ± 19 g kg^{-1} in the middle lane between the tracks (Fründ et al., unpublished data).

Weather data for the years 2013–2015 were obtained from the monitoring site "Solling" of Northwest German Forest Research Institute (NWFVA) at 509 m a.s.l about 8 km northwest from the investigation site. Potential evapotranspiration was estimated from air temperature and global radiation according to Turk and Wendling (in Kappas, 2009). A moving 7-day water balance was calculated as:

$$B_j = \sum_{j-7}^{j} P - \sum_{j-7}^{j} E \quad (1)$$

with j = index number of day from 2013-01-07 to 2015-12-31, P = daily precipitation (mm), E = daily evapotranspiration (mm).

2.2. Water tension

Water tension was measured with Watermark sensors that were permanently installed vertically in 6–10 cm depth (length of sensor is 4 cm). Watermark sensors are based on the principle of water dependent electric conductivity in a granular matrix and are well established in irrigation control (Irrometer company, Riverside CA). Readings were made every two hours and stored in a data logger. The number of sensors installed can be taken from Table 1.

2.3. CO_2-concentration

For continuous monitoring of the soil air CO_2-concentration we used NDIR-sensors (C2-sensor EURO-GAS, Churston Ferrer, UK). The sensor with a measuring range 0–20% CO_2 is housed in a closed cylinder. The sensor opening is attached to a slightly conical nozzle which projects 10 cm from the cylinder and is perforated along 22 mm at the distal end. To place the sensor a small pit was excavated. From there a small auger was driven into the soil at an angle of 13° to the soil surface. The nozzle was inserted tightly into the borehole so that the perforation was at 6 cm soil depth (Fig. 1).

Table 1
Number of sensors for soil water tension (SWT) and CO_2 and number of iron rods installed in untrafficked soil (ctrl), middle lane between tracks and in wheel tracks in the years 2013, 2014 and 2015.

Year	SWT-sensors			CO_2-sensors			Iron rods		
	Ctrl	Mid	Track	Ctrl	Mid	Track	Ctrl	Mid	Track
2013-Apr. 17–Sep. 04	2	6	6	2	2	2	36	12	12
Sep. 04–Oct. 22	11	3	6						
2014	11	3	6	2	2	2	38	11	12
2015	8	2	4	6	6	6	63	14	16