Controlled Traffic Farming improves soil physical parameters

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1. Abstract

Mechanised agriculture increases the risk of soil compaction, especially under humid climates. Controlled Traffic Farming (CTF), relying on permanent tramlines for all farming operations makes it possible to establish and ascertain untrafficked areas on large field areas. In a four-year field trial (randomized blocks; crop rotation: winter wheat, winter barley, forage crop, maize) soil physical parameters were examined in order to determine whether CTF can contribute to the protection and improvement of soil structure. On a loamy soil the treatments “CTF direct drilling”, “random traffic direct drilling” and “random traffic ploughing” were compared. The introduction of CTF influenced the soil physical parameters penetration resistance, macropore volume, O_2-concentration of soil air and matric potential in a positive way. However, absolute values especially of macropore volume of the tested site remained in low ranges. Intensively trafficked tramlines clearly showed the aggravating effect of increased traffic intensity and frequency on soil structure.

Probably due to low stresses in the contact area between soil and tyre, differences between not trafficked and moderately trafficked areas were mostly small. Nevertheless, taking into account that the soil of the experimental field has a very low potential to regenerate an impaired structure, the positive trend of soil physical quality evolution within three years of CTF shows the potential of CTF to support self-recovery of compacted soils and structure formation of carefully managed soils. The findings of the experiment suggest also the adaptation of tillage strategies to the prevailing soil characteristics.

Keywords: Controlled Traffic Farming, tillage, direct drilling, soil compaction, soil porosity

2. Introduction

Agricultural field traffic is one of the main factors determining the evolution of soil structure. Today traffic on agricultural soils is mainly randomly organized. Only for plant protection and fertilizing operations seasonally fixed tramlines are used. Compacted structures of arable soils have to be alleviated with energy, cost and labour intensive tillage operations (Dölger & Jürgens, 2009; Mumme, 2009; Chamen, 2011). A shift from random to systematically planned field traffic would reduce the area affected by consequences of soil compaction such as reduced infiltration rates and water storage capabilities and would make cropping systems more efficient and robust (Hamza & Anderson, 2005; Brandhuber, 2008; Brunotte & Sommer, 2008). Maintaining permanent tramlines over a period of years for all field operations, are referred to as Controlled Traffic Farming (CTF). The use of large working widths, standardised track widths and narrow tyres keeps the percentage of wheeled area low. The risk of soil compaction is therefore confined to a small percentage of the field area, whilst the majority is permanently protected from compaction by field traffic (Webb & Blackwell, 2004; Chamen, 2006).

With random field traffic the risks of water erosion and drought related yield losses are higher than with CTF (Tullberg *et al.,* 2007). Introduction of CTF improved soil structure and plant emergence; the availability of nutrients and water increased, rooting became more intense; yields became more robust against varying weather conditions and increased in general by 5-15 % (Raper *et al.,* 1994; Chamen *et al.,* 2003; Tullberg *et al.,* 2003; Webb & Blackwell, 2004; Tullberg *et al.,* 2007).

In British studies field traffic caused an increase in soil bulk density (+15 %) and soil penetration resistance (+47 %) and a decrease in soil porosity (-10 %) and infiltration capacity (-75 %). Non-trafficked areas had up to 36 % more yield than areas with random traffic. In a review of European CTF and compaction trials the yield on untrafficked areas reached 80-160 % compared to trafficked ones; permanent tramlines always had the lowest yields. It is concluded that CTF under Middle European cropping conditions might lead to a general yield increase of 5-8 % (Chamen, 2006, 2007, 2009, 2011).

In the mid- 2000s conducted studies on grassland in Denmark showed that trafficked areas delivered 10 % less yield than untrafficked ones. In earlier trials traffic reduced yields by 10-60 % depending on the number of machinery passes and tyre inflation pressure (Pedersen, 2008; Green *et al.,* 2010).

Agroscope examined the potential of CTF and its influences on soil physical parameters under Swiss conditions in a field trial at Ettenhausen.

3. Materials and Methods

3.1. Site conditions of the field trial

The field trial was located at Ettenhausen, Switzerland (coordinates E8°54‘22‘‘/N47°28‘53‘‘, altitude 539 m asl). The soil is characterised as a loam and belongs to the Alfisols according to the Soil Taxonomy of the United States Department of Agriculture. It has a stone content of approx. 10 %. Basic soil characteristics are shown in Table 1.

Table 1. Soil characteristics of the field trial.

Parameter	Depth 0.00- 0.20 m	Depth 0.30-0.50 m
Clay	21.9%	24.9%
Silt	33.8%	33.2%
Sand	41.5%	41.9%
org. C	1.6%	-
pH (H_2O)	6.6	6.8

X-ray diffraction analysis (Kühn, 2014) showed that the clay fraction of this soil mainly consists of the minerals Illit, Kaolinit and Chlorit. The swelling-shrinking capacity of these clay minerals is low to zero. Cation exchange capacity of the clay fraction is between 230 to 386 mmolc/kg and indicates a low swelling-shrinking capacity too.

The meteorological reference values for the experimental site at Tänikon (data from 1981 to 2010) show an average annual temperature of 8.7°C with 1184 mm of precipitation. The crop rotation for 2009 to 2012 was winter wheat - winter barley - forage crop (grass-clover-mixture) - silage maize.

The CTF field trial was installed within the experimental design of a long-term field trial on cropping systems, being conducted since 1998. In that long-term field trial the treatments “mouldboard ploughing”, “direct drilling” and “shallow tillage” (8 cm depth) had been compared in a randomized block design with four repetitions on a surface of 0.8 hectare. Generally field traffic was organised as random traffic farming (RTF), with the exception of tramlines for spraying and fertilizing. For the duration of the CTF field trial the existing mouldboard ploughing and direct drilling treatments of the long-term field trial were continued as “random traffic ploughing” (RPL) and “random traffic direct drilling” (RDD). The treatment shallow tillage of the long-term field trial, which was randomly trafficked the last time in 2007, was converted to “CTF direct drilling” (CDD).

3.2. Treatments and tillage implements

In RPL a mouldboard plough with a working depth of 25 cm was used. Seedbed preparation (8 cm depth) and drilling were done with a three-point rear mounted rotary harrow seed drill combination (harrow NG18 with drill DA-L, Kverneland, Kvernaland, NO). Direct drilling was done by means of a disc seeder with 2.25 m working width (Directa, Gaspardo, Morsano al Tagliamento, Italy). In the last experimental year 2012 maize was seeded with a precision seed drill with six rows and 4.50 m working width (NG plus 4, Monosem, Largeasse, France). Details of all used machines are listed in (Holpp, 2012).

For CDD the CTF tramline system ‘Twin Trac’ with two track widths (Chamen, 2006) was chosen. The wider track of the combine straddles adjacent passages of the narrower tractor track (Figure 1).

In order to distinguish properly between differently trafficked areas, the CDD plots were divided into two traffic areas: (1) not trafficked (NOT), (2) moderately trafficked (MOD) and intensively trafficked with tramlines for spraying/fertilizing (INT). The moderately trafficked tramlines were used for seeding and harvesting operations. In cereals and maize this occurred twice a year, in forage crops five times. Table 2 gives an overview of the experimental treatments.

Table 2: Overview of the five experimental treatments in the CTF field trial.

Controlled traffic direct drilling (CDD)			Random traffic direct drilling (RDD)	Random traffic mouldboard plough (RPL)
Not trafficked (NOT)	Moderately trafficked (MOD)	Intensively trafficked (INT)	-	-
CDD-NOT	CDD-MOD	CDD-INT	RDD	RPL

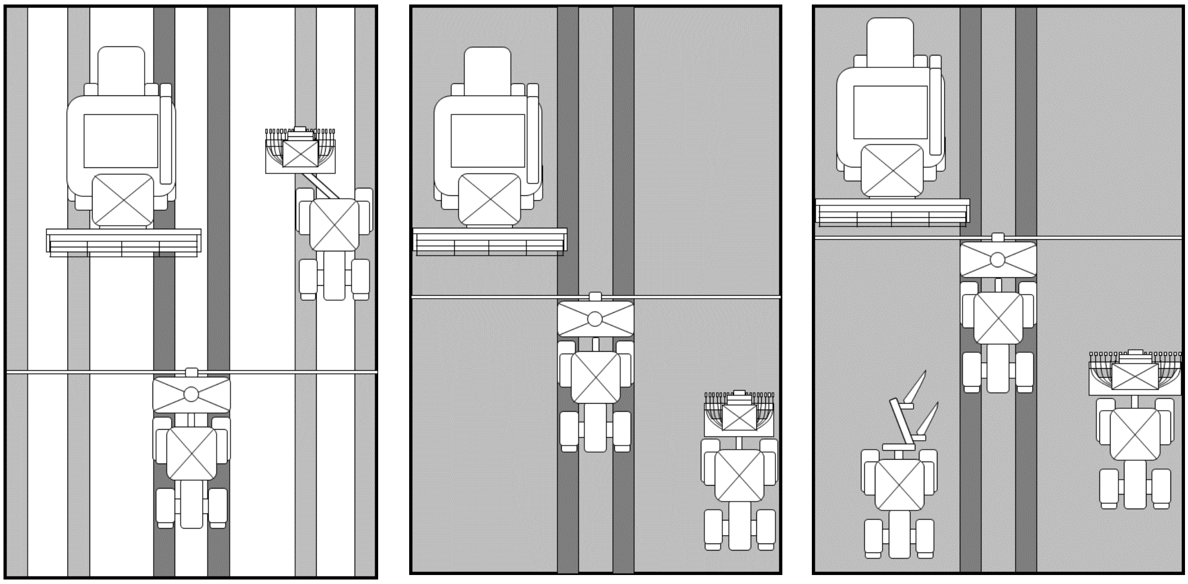


Figure 1: Tramline layout, from left to right: Controlled traffic direct drilling (CDD), random traffic direct drilling (RDD), and random traffic mouldboard plough (RPL). Dark grey = intensively trafficked tramlines for spraying and fertilizing operations; pale grey = area with tramlines for seeding and harvesting operations = moderately trafficked tramlines; white = not trafficked areas in CDD

3.3. Measurements of soil parameters

Soil penetration resistance was determined from 2008 to 2010 after seeding as well as after the last forage crop harvest in 2011 using a hand held Panda-1 penetrometer with a 4 cm^2 cone and a cone angle of 60° (Panda-1, Sol Solution, Riom, France). For every treatment six penetrations from 0 to 0.35 m depth have were done in each of the four blocks.

Soil core samples (471 cm^3 volume) were taken in spring of the years 2009 to 2011 at 0.10-0.16 m soil depth. Due to the high stone content of the plots, only two of the four blocks could be sampled. For every treatment eight samples were collected in each block. All measurements were performed according to the reference methods of the Swiss Agricultural Research Stations (Eidg. Forschungsanstalten 1998).

Soil matric tension was measured directly in the field with pF-Meter probes (ecoTech, Bonn/Germany) in the treatments CDD-NOT and CDD-MOD at 0.10 m and 0.35 m depth, respectively. Three probes have been installed 2009/2010 in each of the blocks 1 & 2, and 2011/2012 additionally in block 3. Volumetric soil water content was measured with frequency-domain-reflection based EnviroSCAN probes (Sentek, Stepney/Australia) in the treatments CDD-NOT and CDD-MOD at 0.10 m and 0.40 m depth respectively. Two probes have been installed 2009/2010 in each of the blocks 1 & 2 and 2011/2012 in block 3. Data from both sensor types were registered by data loggers (CR800/1000, Campbell Scientific, Logan/Utah/USA) every 30 min.

Oxygen concentrations in soil air were measured in the treatments CDD-NOT and CDD-MOD. Semi-permeable polypropylene tubes (Accurel PP V8/2 HF, Membrana GmbH, Wuppertal, Germany) of 0.40 m length were installed at 0.10 m, 0.20 m and 0.35 m depth, each in four repetitions per block. In 2009 and 2010 blocks 1 and 2 were equipped, in 2011 and 2012 blocks 1, 2 and 3. Soil air was analysed weekly directly in the field with a CheckMate 9900 (PBI Dan-sensor A/S, Ringsted, Denmark).

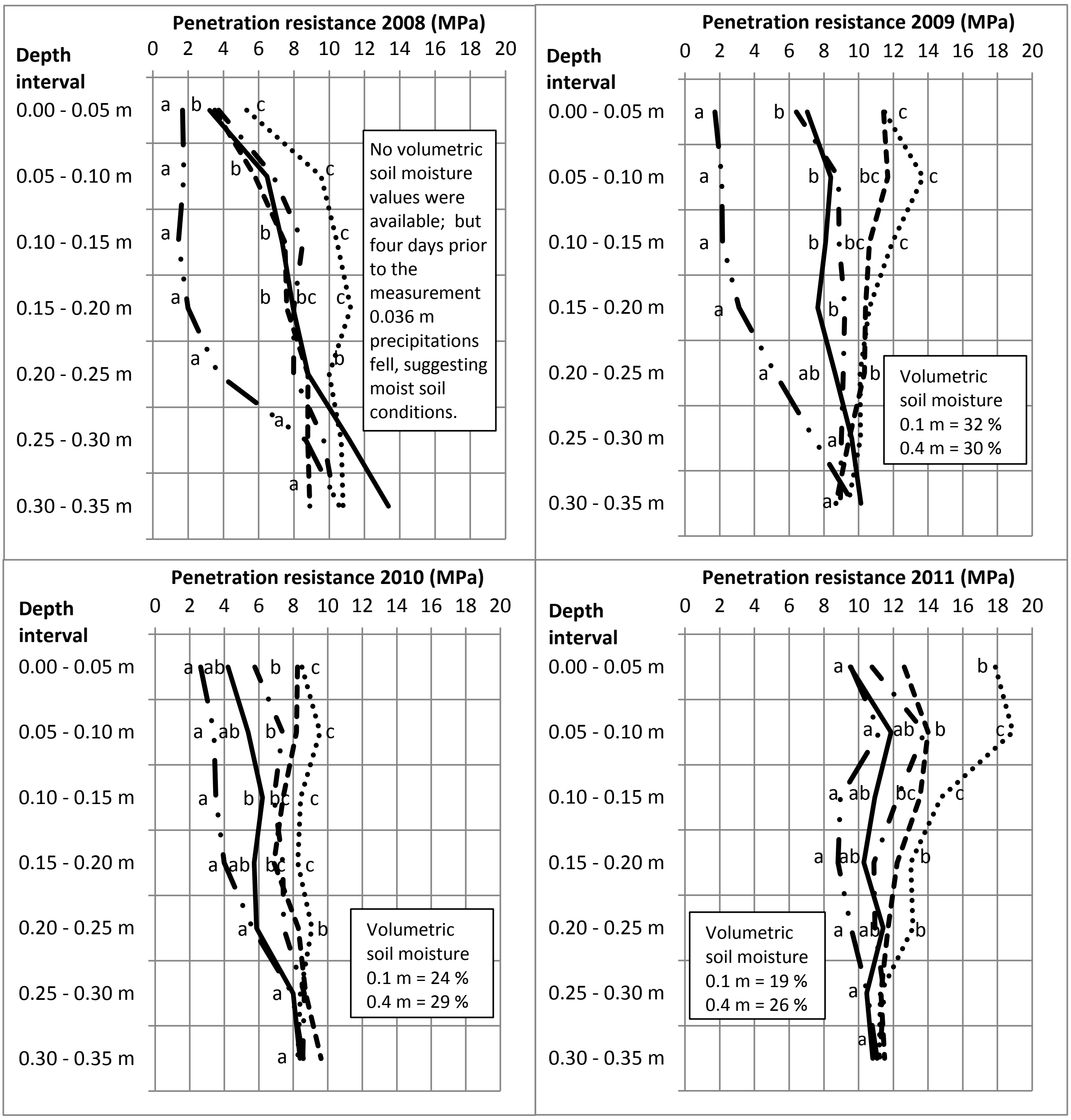
The randomized block design of the field experiment was analysed with fixed-effects ANOVA by using the software. TIBCO Spotfire S+® 8.1 for Windows (TIBCO Software Inc., Palo Alto, California, USA).

4. Results

4.1. Penetration resistance

In 2008 the different treatments were statistically not different (Figure 2) with the exception of CDD-INT. Over the years values for penetration resistance in the topsoil started to differ between the treatments. RPL had the lowest values followed by CDD-NOT, RDD, CDD-MOD and CDD-INT.

Over the whole experimental period from 2008 to 2011 RPL had the lowest penetration resistance values in the topsoil. In 2011, after four forage crop harvests, penetration resistance in the topsoil of RDD and CDD-NOT were no longer statistically different. Differences in penetration resistance between CDD treatments and RDD disappeared starting at 0.20 m depth.



— ●● — RPL / — ● — RDD / —— CDD-NOT / — — CDD-MOD / ●●● CDD-INT

Figure 2: Soil penetration resistance measurements in winter wheat (2008), winter barley (2009), forage crops (2010) and silage maize (2011). Statistical comparisons within years and depth intervals: letters a, b and c characterise statistically different groups.

4.2. Macropore volume

In 2009, 2010 and 2012 soil macropore volume in direct drilled plots was substantially lower than in ploughed plots (Figure 3). In 2011, when a cultivator was used instead of a plough, soil macropore volume in RPL was similar to the direct drilled treatments. Over the years soil macropore volumes in direct drilled plots ranged from 3.7 % to 9.1 %. CDD-NOT showed in general slightly higher values than CDD-MOD and CDD-INT; however, differences between treatments were small. All treatments showed a trend for soil macropore volume decrease from 2009 to 2011, followed by an increase in 2012.

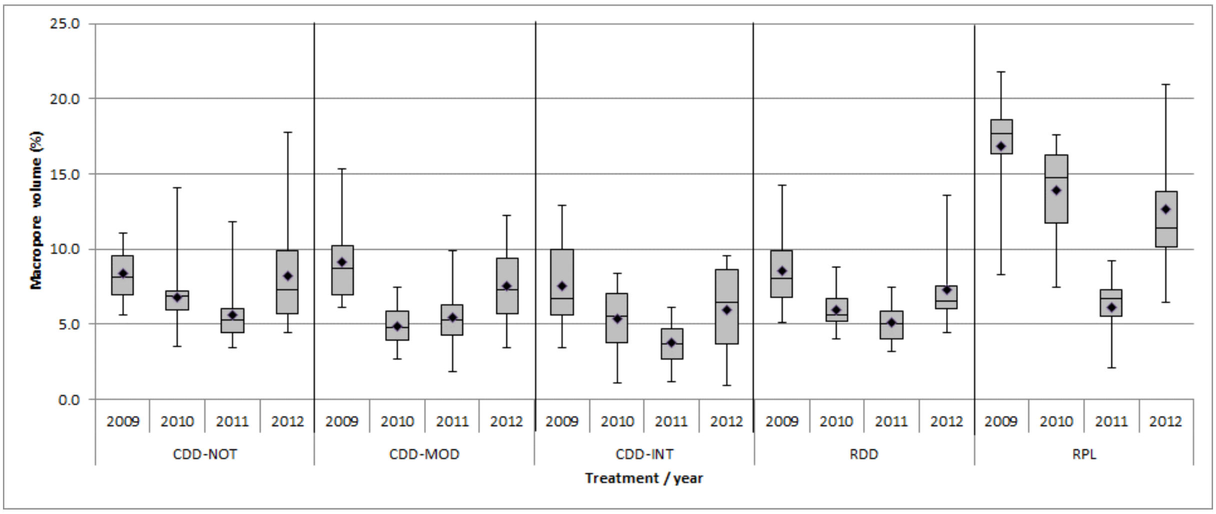


Figure 3. Macropore volume at 0.10-0.16 m depth. Each boxplot represents the values of 16 soil core samples (2 blocks with 8 repetitions each). The horizontal bar corresponds to the median, the box spans over the second and the third quartile; the whiskers indicate minimum and maximum values; the black rectangular dot shows the mean.

4.3. Matric potential and volumetric soil water content

The relation between volumetric soil water content and matric potential as well as soil pore distribution of the treatments CDD-NOT and CDD-MOD in the top soil (0.10 m depth) are shown in Figure 4. In this field desorption curve the volumetric soil water content is plotted against the matric potential simultaneously measured in the field. For statistical analysis matric potential values were pooled to matric potential classes and assigned to respective macropore sizes (< 2 pF = macropores; 2-3 pF = coarse mesopores, > 3 pF = fine mesopores and micropores).

In the topsoil the two treatments showed a very similar relation between matric potential and volumetric water content in winter barley 2010, indicating a similar soil structure. In forage crop 2011 the field desorption curves started to differentiate between the two treatments. In CDD-NOT both macropore and coarse mesopore volume increased and summed up to additional 5 % than in the year before, whilst in CDD-MOD these pore size classes did not change substantially. The differentiation between these treatments became even more evident in the following year 2012 (silage maize). Finally CDD-NOT had 24 % macropore and coarse mesopore volume compared to 14 % in CDD-MOD.

In the subsoil soil structure evolution between treatments was different. In all three years 2010 to 2012 desorption curves for subsoils didn’t show any statistically relevant differences between the two treatments (data not shown), meaning that subsoil structure was similar in both treatments.

Maximum matric potential measured in the subsoil was pF 3.7 for CDD-NOT and pF 3.2 for CDD-MOD. The longest period with pF values higher than 3 lasted for both CDD-NOT and CDD-MOD during 34 days from April 27th to May 30th 2011 in forage crops. The other two occurrences with high matric potential were peak events with a duration of two days and pF values of 3.0 to 3.1.

4.4. Soil air

O_2-concentrations in soil air (Figure 5) were in all treatments and depths higher than 10 %. With the exception of 2012 moderate traffic treatment “MOD” decreased soil oxygen content significantly at 10 and 20 cm depth compared to untrafficked “NOT”. At 35 cm depth the differences were less pronounced than in the upper two soil layers.

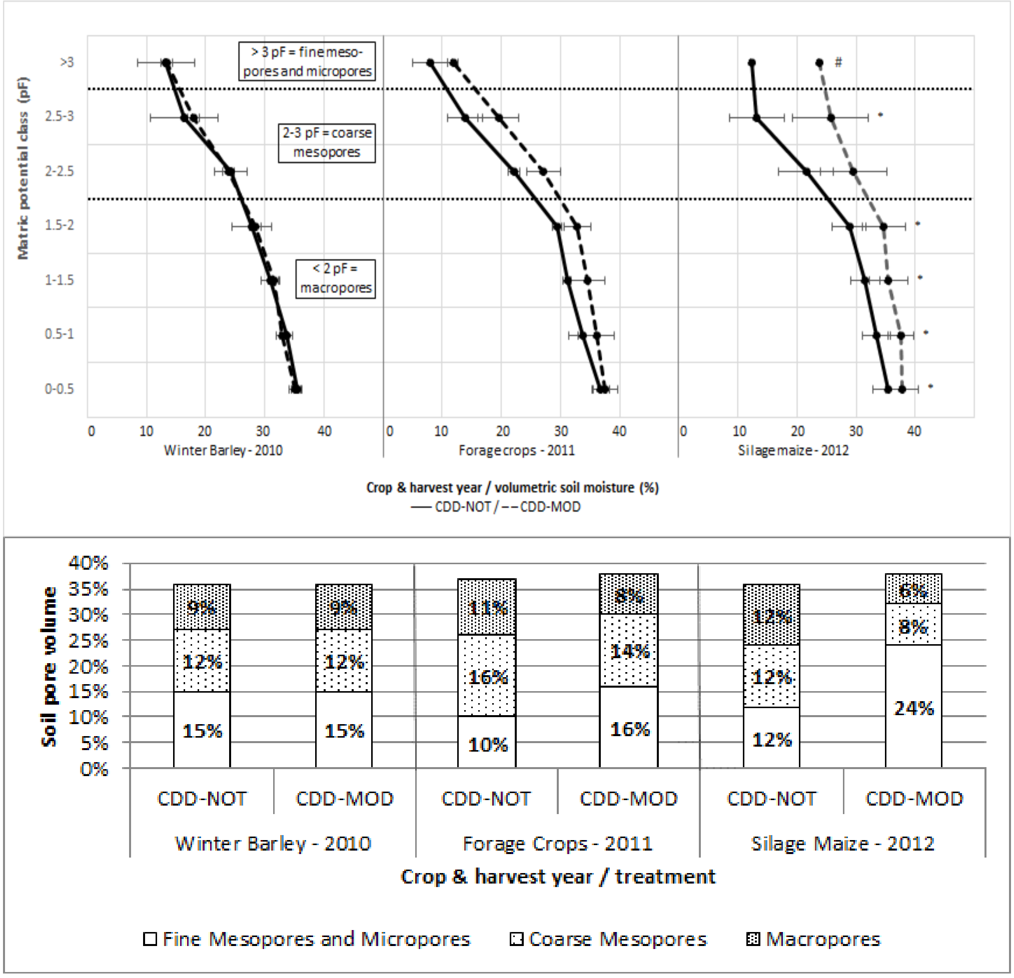


Figure 4: Relation between classified volumetric water content and matric potential at 10 cm depth measured in the field from 2010 to 2012 in CDD-NOT and CDD-MOD. The assignment of matric potential classes to respective macropore sizes is: < pF 2 = macropores; pF 2-3 = coarse mesopores, > pF 3 = fine mesopores and micropores. *: $\alpha < 0.05$; #: not enough values for statistical analysis available

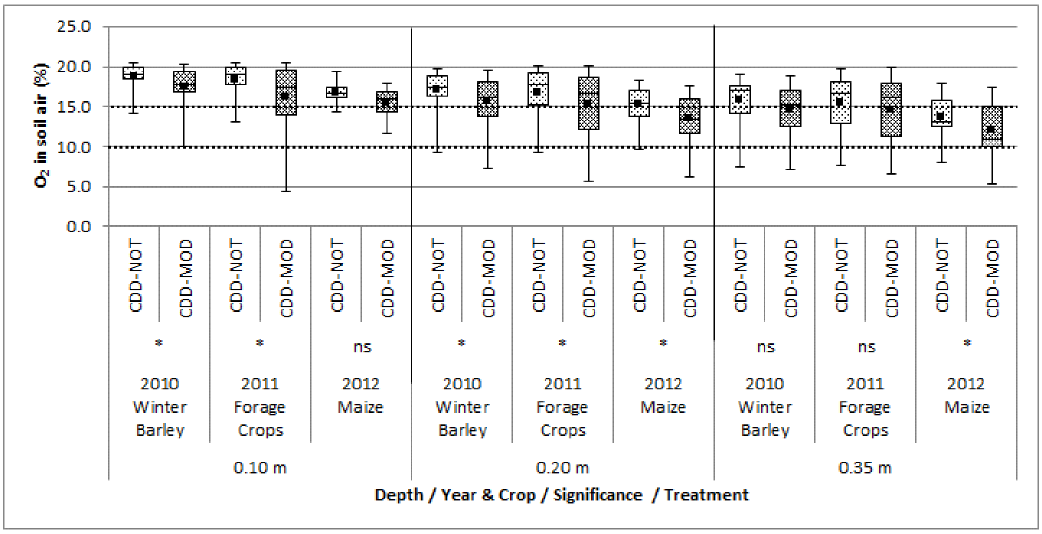


Figure 5. Oxygen (O_2) concentrations in soil air at the three depths 0.10 m, 0.20 m and 0.35 m. The horizontal bar corresponds to the median, the box spans over the second and the third quartile; the whiskers indicate minimum and maximum values; the black rectangular dot shows the mean. * = $\alpha < 0.05$, ns = not significant

5. Discussion

Soil penetration resistance development clearly illustrated the various traffic intensities. The direct drilling treatments CDD and RDD started with very similar soil penetration curves and differentiated over the years according to the stresses imposed. Maximum values for penetration resistance were observed in the 0.05-0.10 m layer. Lower values in CDD-NOT compared to CDD-MOD show that even modest traffic intensities with two annual machinery passes under dry conditions result in clearly measurable soil compaction effects. In the RDD treatment the field area was partially trafficked and partially untrafficked. Thus it is in line that the measured penetration resistance values lie between the ones of CDD-NOT and CDD-MOD.

Over the years soil macropore volume shows a less pronounced development than penetration resistance measurements. Soil macropore volume is on a low level like in other direct drilling field trials (Bischoff & Hofmann, 2007; Stahl, *et al.* 2009). The Swiss Soil Science Society recommends a soil macropore volume of 7 % as "threshold value" and of 5 % as critical "action value" (Buchter & Häusler, 2009). With average values between 3-9 %, the direct drilling treatments are generally near to the threshold value and often around or below the critical action value. This partially explains the depressions of plant yields of this trial which have been published in Holpp (2012).

The dynamics of soil structure evolution can be followed over the years. It is remarkable that soil macropore volume remained on low levels even under an untrafficked long-term direct drilling regime. In comparable direct drilling field trials macropore volume showed an evolution towards 10 % soil macropore volume (Weisskopf *et al.* 2005). It was expected that a soil with a clay content of 22-25 % should have a high structural regeneration capability. However, analysis of the swelling-shrinking capacity of the clay minerals in the soil of the experimental field explain the observed evolution of soil structure: the clay fraction has a low swelling-shrinking capacity. Consequently the potential for structural regeneration of the soil is very limited (Kühn, 2014).

Matric potential in the top- and the subsoils was always distinctly below the permanent wilting point of pF 4.2. Only in 2011 (forage crops) matric potential was in both top- and subsoils above pF 3.5 during a longer period without precipitations. Thus water supply never became a critical parameter for plant growth during the experimental period. The differences in soil matric potential being monitored at 0.10 m depth in maize 2012 are a result of considerable impacts of high traffic intensity on soil structure during forage crop cultivation in 2011.

Field measurements of volumetric soil water content showed a maximum water content of the experimental soil of about 36 %. This corresponds well to values of total porosity in the range of 37 % measured by means of soil cores (data not shown). The relation between volumetric water content and matric potential ("field desorption curve") shows the effect of traffic on soil structure and thus on soil pore distribution. Plant roots can easily access water in macropores and coarse mesopores. In CDD-MOD 14 % pore space belong to this class. With 24 % this value is considerably higher in CDD-NOT. It's not yet understood why the measured field desorption curves indicate much higher differences between the treatments than the soil cores did. This methodological aspect needs deeper investigation.

O_2-concentrations were in all treatments and soil depths higher than 10 %, which is often assumed to be the threshold value for plant root development (Geisler, 1978; Scheffer & Schachtschabel, 2002). Single values below 10 % showed that some limitations especially during wet periods occurred.

The investigated parameters O_2-concentration in soil air, soil penetration resistance, soil macropore volume determined by means of soil cores and field desorption curves corroborate the negative effects of field traffic on soil physical parameters. Whereas penetration resistance and the field desorption curves showed high differences with significant results, soil cores and O_2-concentrations in soil air showed smaller but still significant differences.

6. Conclusion

Introduction of CTF in a running long-term field experiment influenced penetration resistance, macropore volume and O_2-concentration in soil air in a positive way. Probably due to low stresses in the contact surfaces between tyres and soil, the short experimental period of 3 years, the low swelling-shrinking capacity of the present soil, the differences between soil structure of untrafficked and moderately trafficked areas were mostly small. Intensively trafficked tramlines clearly showed the aggravating effect of increased traffic intensity on soil structure.

The improved water availability for plants and the increased macroporosity in the untrafficked areas can be interpreted as enhanced resilience regarding climate change. The improved soil structure allows for a better plant development during dry periods and better infiltration capacities during intense rainfall events.

The positive evolution of soil physical parameters within three years demonstrates the general potential of controlled traffic farming to protect soils from detrimental impacts and to support self recovery of compacted soils. By decreasing the risk of soil compaction CTF reduces the need for soil tillage which is always conjoined with higher operation costs and fuel consumption.

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