SOIL AND PLANT RESPONSES TO CONTROLLED TRAFFIC FARMING IN SWITZERLAND

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Abstract

A long-term tillage experiment in Tänikon, Switzerland showed that compared to ploughed plots, untilled plots developed a compact soil structure with decreased porosity and a trend towards lower oxygen concentration in the soil air. All these factors resulted in lower plant yields. To investigate the influence of wheeling on these plots, the shallow-tilled plots were converted to controlled traffic farming (CTF) with no-tillage in 2008. The hypothesis is that a sustainable improvement in soil structure and plant development is achievable in areas with no traffic.
In a field trial with four repeated blocks, 'CTF no-tillage' was compared with 'random trafficked mouldboard ploughing' and 'random trafficked no-tillage'. The crop rotation was winter wheat – winter barley – meadow, established on luvisol (23% clay, 34% silt, 42% sand) with an annual rainfall of 1190mm and an average annual temperature of 8.4 °C. An intensive monitoring programme was set up for various parameters: Soil-surface-level changes, penetration resistance, macropore volume, soil-air composition, matric potential, volumetric soil-water content, emergence rate, intermediate harvests and harvest yield.
Results for 2008 to 2011 show that traffic has a clearly negative impact on soil structure in all variants, even when wheelings are done with low tyre-inflation pressure. Traffic-induced soil-surface-level changes were small, but nonetheless affected the soil's physical parameters. Soil penetration resistance is higher and soil oxygen content after precipitations lower in the trafficked areas than in traffic-free zones. Yield effects were not as pronounced as in other published field trials. CTF and no-tillage achieved approximately the same yield levels, but routine ploughing resulted in the highest yields. CTF leads to a certain improvement in the soil structure, but the plant response showed that more improvement is necessary to optimise yields.

Key words: no-till, soil compaction, plant development, controlled traffic farming

1. Introduction

The main problem with no-tillage and minimum tillage techniques is the lower yield, commonly caused by reduced emergence and delayed early development of plants as a result of compacted structures in the topsoil (Anken et al. 2004; Anken et al. 2006). In addition to the negative agronomic impact of this compaction, it also promotes nutrient leaching and soil erosion (Elsässer 2001).
In Controlled Traffic Farming (CTF), all work is carried out from permanent traffic lanes based on Global Navigation Satellite Systems (GNSS) driven steering systems and closely matched machine widths. There is never any field traffic on the soil between traffic lanes and the topsoil is never compacted (Chamen 2006; Webb & Blackwell 2004; Hamza & Anderson 2005). Air and water flow are improved and the soil is better able to buffer both heavy precipitation and periods of drought (Alakukku et al. 2003). In Australia today, several million hectares of wheat and sugarcane are managed using CTF. Results from Great Britain and the Netherlands suggest that even under central European conditions, CTF can sustainably
improve the efficiency of plant cultivation (Chamen et al. 2003; Vermeulen & Korteweg 2007).
To investigate the potential of CTF a field trial is conducted from 2008-2013. The aim is to determine whether CTF can sustainably improve the efficiency of cropping systems.

2. Materials and methods

2.1. Experimental area

The CTF field trial was incorporated into a tillage system comparison which has been ongoing since 1998. CTF direct drilling (*CTF*) was installed on formerly shallow tilled (max. 8cm depth) plots. It was compared with the conventionally random trafficked variants direct drilling (*Direct Drilling*) and mouldboard ploughing (Plough) being under these cultivation regimes since 1998. The trial was run as a randomized block design with four replications.

2.2. Design of CTF variant

The land was divided into three traffic zones: *no traffic* (yellow), *medium traffic* (pale grey) and *intensive traffic* (dark grey). The *medium traffic* area was driven on only twice a year, during soil tillage/seeding and harvesting. The *intensive traffic* area coincided with today's existing cultivation lanes. Depending on the working width the *no traffic* area takes up approx. 67% of the surface, the *medium traffic* area 27% and the *intensive traffic* cultivation lanes 6% (Fig. 1). In order to distinguish properly between differently trafficked zones, Plough and Direct Drilling were also divided into areas with *random traffic* and *intensive traffic*. (Table 1).

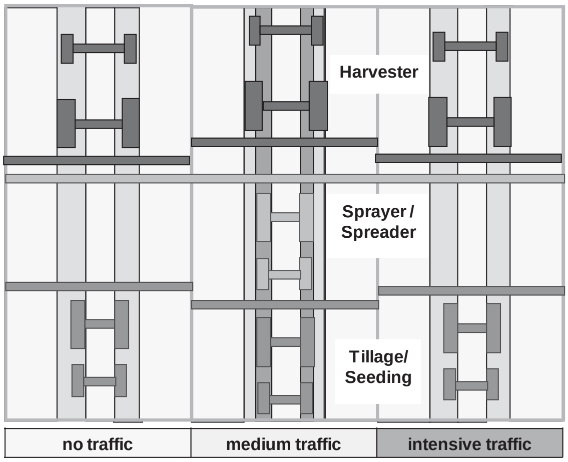

FIGURE 1. CTF traffic zones.

TABLE 1. List of trial variants.

Tillage system	Traffic intensity		
	no traffic	medium / random traffic	intensive traffic
Direct Drilling	CTF no traffic	CTF medium traffic	CTF intensive traffic
	-	Direct Drilling random traffic	Direct Drilling intensive traffic
Plough	-	Plough random traffic	Plough intensive traffic

2.2. Crop rotation 2008-2011

The crops grown were winter wheat (harvesting year (HY) 2009), winter barley (HY 2010) and forage crops (HY 2011). Forage crop cultivation with four to six harvests per season involved considerably more passages and a heavier load on traffic lanes. The suitability of CTF for grassland systems could be assessed in this way.

2.3 Tyre inflation pressure

In accordance with good agricultural practices, all tractors operated with a tyre inflation pressure of 80 kPa and the combine harvester with 100 kPa at the front axle and 120 kPa at the rear axle. (Table 2).

TABLE 2: Overview of tractors, combine harvester with tyres and inflation pressures used.

Machine	Unladen weight	Front axle		Rear axle	
		Tyres	inflation pressure	Tyres	inflation pressure
Same Dorado 75 sprayer, spreader	3,950kg	360/70R20	80 kPa	420/70R30	80 kPa
John Deere 6920S no-till seed drill	7,320kg	540/65R28	80 kPa	650/65R38	80 kPa
Fendt 411 cultivator / seed drill	5,770kg	420/70R24	80 kPa	460/85R34	80 kPa
John Deere 2254: combine harvester	12,900kg	800/65R32	100 kPa	540/65R24	120 kPa

2.3. Monitored parameters

Surface survey: In order to determine the differences in soil height caused by field traffic, the soil surface of the plots was surveyed in September 2008-2011 prior to seeding with a tachymeter (TCRP 1202 R300, Leica-Geosystems, Heerbrugg, Switzerland) which has a measuring accuracy of +/- 1.5mm.

Soil penetration resistance of a 4cm^2 cone was determined after seeding in 2008-2010 and after the last harvest of 2011 with a hand held Panda-1 penetrometer (Panda-1, Sol Solution, Riom, France).

Macropore volume was determined using core samples (10cm diameter, 6cm height, 471cm^3), taken at depths of 10-16cm in Spring 2009-11. Due to the high stone content of the plots only two of the four blocks could be sampled.

Emergence rate: For winter wheat and winter barley the emergence rate was determined.

Harvests: For winter wheat and winter barley the biomass was determined during the growing periods in mid-April and after the final harvest. Due to a hailstorm in May 2009 no final harvest was possible for winter wheat. The hand harvest for winter barley 2010 and grass/clover 2011 took place some days before the regular harvest.

Oxygen content of the soil air was analyzed by using horizontal 50 cm long Gore-Tex pipes (Gut et al. 1998) permanently installed in the field at a depth of 10 cm. Three tubes per plot were installed in three blocks.

3. Results

3.1 Surface survey

In all variants, traffic induced surface level decrease remained on a low level. Maximum differences of 12mm were monitored in *CTF intensive traffic*. No deep ruts were observed. *CTF no traffic*, *Direct Drilling random traffic* and *Direct Drilling intensive traffic* did not differ significantly. 2009 and 2010 *CTF medium traffic* had the highest surface level decrease. This could be related to the previous shallow tillage regime with a higher compaction potential. But after pasture in 2011 it did not differ significantly from *CTF no traffic*, *Direct Drilling random traffic* and *Direct Drilling intensive traffic.* However, *CTF intensive traffic* remained compacted and did not recover under pasture.

3.2 Soil penetration resistance

As expected *Plough random traffic* from 2008-2010 had the lowest penetration resistance values. In 2008 *CTF no traffic*, *CTF medium traffic* and *Direct Drilling random traffic* were on the same level. From 2009 to 2010 the values show a clear tendency towards a differentiation. In 2010 *Plough random traffic* showed the lowest penetration resistance, followed by *CTF no traffic*, *Direct Drilling random traffic*, *CTF medium traffic* and *CTF intensive traffic* (Fig. 2).

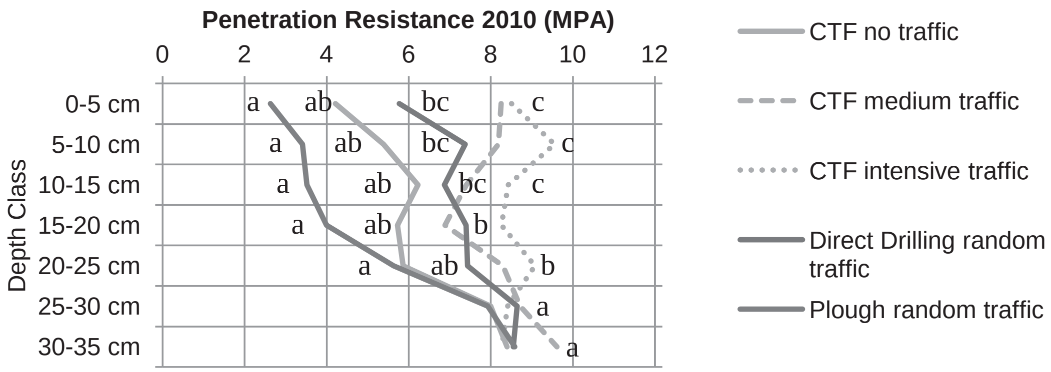

FIGURE 2: Penetration resistance after seeding 2010.

3.3 Macropore volume

In 2009 *Plough random traffic* had approx. 16% macropore volume. This was roughly twice as high as *Direct Drilling* and *CTF* variants. Over the years, results have shown a trend of steady decline in the macropore volume. *Direct Drilling*, *CTF no traffic* and *CTF medium traffic* dropped from ~8% to ~5%. *CTF intensive traffic* had the lowest overall macropore volume with around 3.5%.

3.4 Soil oxygen content

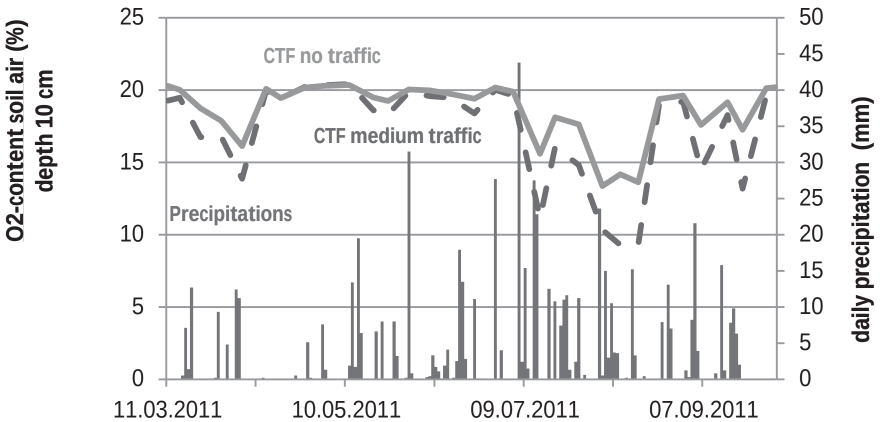

FIGURE 3: Daily precipitation and O2-content of the soil air in trafficked and untrafficked CTF-variants.

Traffic and precipitation are influencing the concentration of oxygen in the soil air (Fig. 3). High precipitation led to a decrease in all variants, but the trafficked zones showed a stronger decline when compared to the untrafficked. Individual values in CTF medium traffic (not shown) reached levels of below 5 % O2 which characterizes anaerobic conditions.

3.5 Emergence rate

Emergence rate for winter wheat in 2008 was heterogeneous. CTF no traffic and CTF medium traffic had the lowest values with just under 200 plants/m2 and Plough random traffic the highest with 300 plants/m2. These differences were statistically significant. Direct drilling random traffic was in between and did not differ significantly from CTF and Plough. For winter barley in 2009 there were no differences between the variants with values ranging from 145 to 170 plants/m2.

3.6 Harvests

For the 2009 winter wheat harvest the average dry matter figures for the intermediate harvest in CTF no traffic, CTF medium traffic and Direct Drilling random traffic were similar ~85g/m2. Due to winterkill damage, figures for

Plough random traffic had dropped significantly to ~53g/m2. The 2010 winter barley values ranged from 83 to 116g/m2 and did not differ significantly among variants.
As mentioned earlier there was no final harvest possible in winter wheat due to a hailstorm in May 2009. In 2010 the winter barley Plough random traffic had a higher dry mass yield in final harvest than CTF no traffic, CTF medium traffic and Direct Drilling random traffic. Statistical analysis showed that CTF no traffic did not differ significantly from Plough random traffic and Direct Drilling random traffic. CTF medium traffic had significantly lower values than all other variants. In the 2011 pasture harvest CTF intensive traffic was also sampled. CTF intensive traffic was found to have had a significantly lower yield than other zones and Plough random traffic the highest. The other variants were in between (Fig. 4).

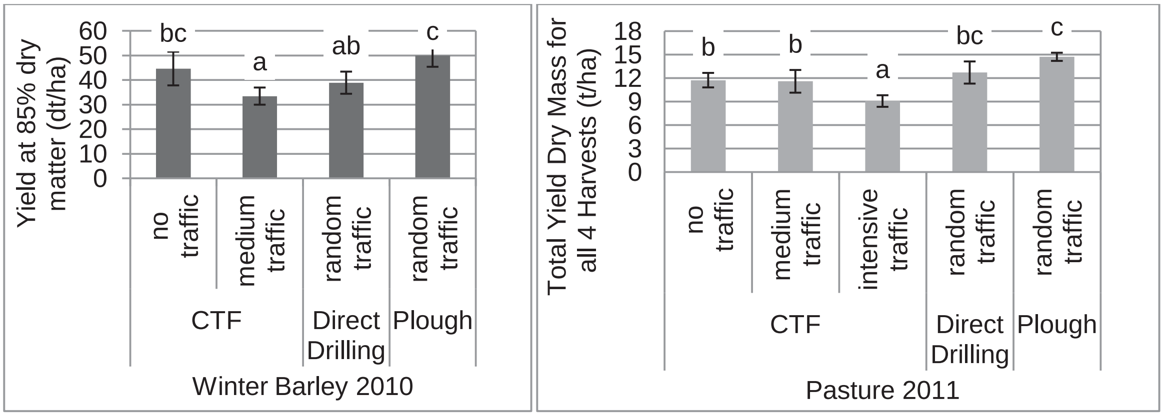

FIGURE 4: Winter barley yield 2010 and pasture yield 2011

4. Discussion

4.1 Soil physical parameters

The variants *CTF* and *Direct Drilling* were cultivated with the same type of seeding equipment, only the driving strategy (controlled/random) differed. However, due to the historical background of the trial field the soil conditions for CTF and *Direct Drilling* were not identical. *CTF* plots were shallow tilled (8cm) until 2007 and *Direct Drilling* plots remain untilled since 1998. Spade testing confirmed differences in soil structural development. Most notably, the topsoil of *Direct Drilling* had a more crumbly structure and did not show any compaction horizons induced by former tillage. The soil structure of the *CTF* variants did not show a final, mature stage after three years CTF practice.
The soil surface level decreases observed in *CTF* variants were interlinked with penetration resistance and macropore volume. Penetration resistance values showed that the majority of compaction effects from field traffic were in the top soil, up to 20cm depths. The layer from 5-10cm showed maximum values and was quite dense. Further compaction had taken place in less dense areas. A soil surface level decrease of some millimeters might have reduced the macropore volume between 10-16cm substantially. *CTF no traffic* showed the lowest surface level decrease and the lowest penetration resistance. This coincided with the oxygen content of the soil air which was higher without traffic. This indicates a higher gas exchange rate facilitated by a less compacted soil structure.
The fact that *CTF medium traffic* and *Direct Drilling* random traffic have comparable penetration resistance and macropore volume values indicates that these two variants develop similarly. The soil's physical parameters did not differ much but clearly showed that traffic is compacting soil structure.

4.2 Plant related parameters

Emergence rates sometimes differed depending on seeding methods but were regular overall. Plant development until the final harvest was identical, with the exception of lower *Plough random traffic* values 2009 due to winterkill damage. In the winter barley harvest of 2010 and pasture harvests of 2011 the variants differentiated. In 2010 *CTF no traffic* was nearest to

Plough random traffic and in 2011 nearest to *Direct Drilling random traffic*. The fact that *CTF intensive traffic* had the lowest yield in pasture in 2011 shows the disadvantages of high traffic intensity. European trial results show a yield of around 80-160% for non-traffic areas compared to trafficked; from Australia, where CTF is mainly spread under semiarid cropping conditions, 100-190% are reported (Chamen 2006). These numbers indicate that the variation in yield response is high as these parameters depend on many other parameters as well as the soil's physical conditions.

5. Conclusion

The absence of traffic in CTF systems caused less surface level decrease, lower penetration resistance and a better gas exchange as expressed by higher oxygen concentrations in the soil air. However, concerning plant and yield development, no clear pattern could be seen as to whether CTF no traffic could perform well in the long term with higher yields than *Direct Drilling* random traffic. Natural soil recreation processes take a long time (CTF plots are only for three years under no till). How long the improvement of the soil structure will take under local pedoclimatical conditions is unanswered. In addition, annual plant and yield development is strongly influenced by other factors such as the course of temperature and precipitations. Beside these considerations, the influence of the low ground pressure tyres used in the experiment should not be neglected as they might have contributed in a substantial way to the results of *CTF medium traffic* and *Direct Drilling random traffic* which were close to *CTF no traffic*.

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