# Controlled Traffic Farming – A Five Years Investigation on Three Locations in Bavaria

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### Abstract

Controlled traffic farming (CTF) systems have been installed and investigated on selected fields of three arable farms in Bavaria. All farm equipment used for the investigations meet German traffic regulations. Therefore it is not able to match track widths of tractors, harvesting machines and implements. Hence the portion of non-trafficked land is limited to 60-70%. RTK DGPS based automatic steering systems where used for all field work. The aim of the investigations was the technical and organisational realisation of CTF on farms under German resp. Bavarian conditions and the determination and analyses of effects on soil physical properties, soil water balance and yield. The modified CTF systems could be technically and organizationally realized. Challenges were matching the working width of different equipment, supplying RTK guidance systems to all equipment, transfer of track positions between different guidance systems and integration of contractor work. Soil structure improved with lower bulk density and higher air capacity in the un-wheeled areas compared to the wheeled areas. Soil water balance and plant available soil water does not differ between un-wheeled and wheeled areas. Winter wheat yields did not react on the differences in soil structure between un-wheeled and wheeled areas. Corn yields significantly reacted on the differences between un-wheeled and wheeled areas.

**Keywords:** Controlled traffic farming, CTF, soil compaction, guidance, soil, yield.

## 1. Introduction

Soil compaction by field trafficking during tillage, seeding, cultivation and harvesting, negatively influences the soil functions. Often this will reduce crop yields. Climate change will increase the requirements on soil functions to deliver high and stable yields. Controlled Traffic Farming (CTF) is a strategy to concentrate field traffic to a limited area of the field and to create a large area without soil stress by wheeling (Chamen et al. 1994). For Australian conditions Tullberg et al. have shown, that CTF can increase water infiltration, reduce erosion and results in higher and more stable yields (Tullberg et al., 2007).

First investigations with consequent controlled traffic farming where carried out in the 70th and 80th of the last century in Dutch vegetable field production using gantries. The expected improvements in soil structure and the reduction of fuel occurred (Lamers et al., 1986), because of technical constraints the new technology was not widely adopted.

Today agricultural research and practice work again on that topic (Tullberg, 2010, 2008, Reeder, 2002). Together with affordable high accuracy GPS based automatic steering systems powerful tractors, wide tillage and planting equipment with 6, 9 or 12 m working width and harvester equipment with identical cutting width make it possible to successfully realize controlled traffic farming.

In Australian crop production on erosion sensitive soils CTF is established as a standard grain production technology on several million hectares (Tullberg et al., 2007, Department of Agriculture, 2004). Scientific investigations show increased water infiltration, improved soil structure, reduced erosion, higher germination rates, more intensive rooting and more stable and higher yields (Kingwell & Fuchsbichler, 2011, Tullberg et al. 2007, Li et al., 2004 a,b). Bowmann (2008) reported economic advantages of CTF under Australian conditions.

Positive effects regarding water efficiency, erosion control, and yield have been also documented for the dry loess soil areas in Northern China (Quingjie et al., 2009).

Today different research groups in Great Britain, Switzerland, Slovakia, the Czech Republic, the Netherlands Denmark and Germany are investigating how controlled traffic farming system can be established under Western and Middle European conditions (soil, climate, rotations, mechanization, yield) and if similar effects can be realized like in dryer regions (Australia, Northern China). For single aspects publications are available (Roberts, 2011, Holpp et al., 2011, Bochtis et al., 2010, Kroulik et al., 2010, Bommes, 2009, Holpp & Anken, 2008), all-embracing scientific research results based on finished field experiments in Europe have not been published until now. In Switzerland the investigations have been finished. Soil parameters were shown to differ into un-wheeled and tracked areas, but differences were fairly slight. Yield did not react as clear as soil parameters, no general agronomic trends could be deduced (Holpp et al. 2013).

Aim of the investigations lasting from summer 2009 until autumn 2014 and summerized in this publication was to adapt controlled traffic farming (CTF) to farm mechanization and farm structures in Germany, to implement modified

CTF systems on selected farms and fields, and to investigate the effects of CTF on soil structure, soil water balance and on yields

## 2. Materials and Methods

Three farms in southern Bavaria, practicing mulch tillage and using automatic guidance systems since several years, which showed interest in controlled traffic farming, were asked and two suitable fields on each of these farms were selected to establish CTF systems with 4.5 m, 5.4 m and 6.0 m system width, according to the available mechanization (Table1).

Table 1. Selected farms and fields for controlled traffic farming experiments 2009-2014

| Farm No. | location | soils | rotation | CTF system width |
|---|---|---|---|---|
| 1 | Eichstaett county<br>430 m absolute altitude<br>average temperature 8.7 °C<br>average precipitation 708 mm/a | silty loam | sugar beet<br>winter wheat<br>winter rye | 5.4 m |
| 2 | Neuburg county<br>450 m absolute altitude<br>average temperature 8.7 °C<br>average precipitation 685 mm/a | silty loam | oilseed seed rape<br>winter wheat<br>winter wheat | 6.0 m |
| 3 | Pfarrkirchen county<br>560 m absolute altitude<br>average temperature 8.9 °C<br>average precipitation 891 mm/a | loamy sand<br>sandy loam | oilseed rape<br>corn<br>winter wheat | 4.5 m |

Precise automatic guidance systems assured that all machines moved exactly on the defined tracks. The tracks stayed fixed during the whole investigation period. The rotation on farm 1 includes winter wheat and sugar beet, on farm 2 winter wheat and oilseed rape, and on farm 3 winter wheat, oilseed rape and corn.

On all three locations extensive soil moisture measurement networks to determine the development of soil water content were installed in the area of the tracks and in the un-wheeled areas and in three depths down to 0.6 m (Figure 1). Repeated sampling and analyzing of soil probes gave information on the differentiation of soil physical properties and yields were separately determined within the tracks and in the un-wheeled areas for small grains and corn.

Figure 1. Installation of soil moisture measurement network.

## 3. Results and Discussion

3.1. Technical implementation and realization

The implementation of CTF on German (Western European) farms requires compromises regarding the track widths and therefore the wheeled area compared to the "ideal" situation reported from Australia. Due to legal restrictions for road transport “twin track” pattern (Chamen 2006) have to be used where the tractors with track width between 2.0 and 2.5 m run alternating to the tracks of the combine (Figure 2).

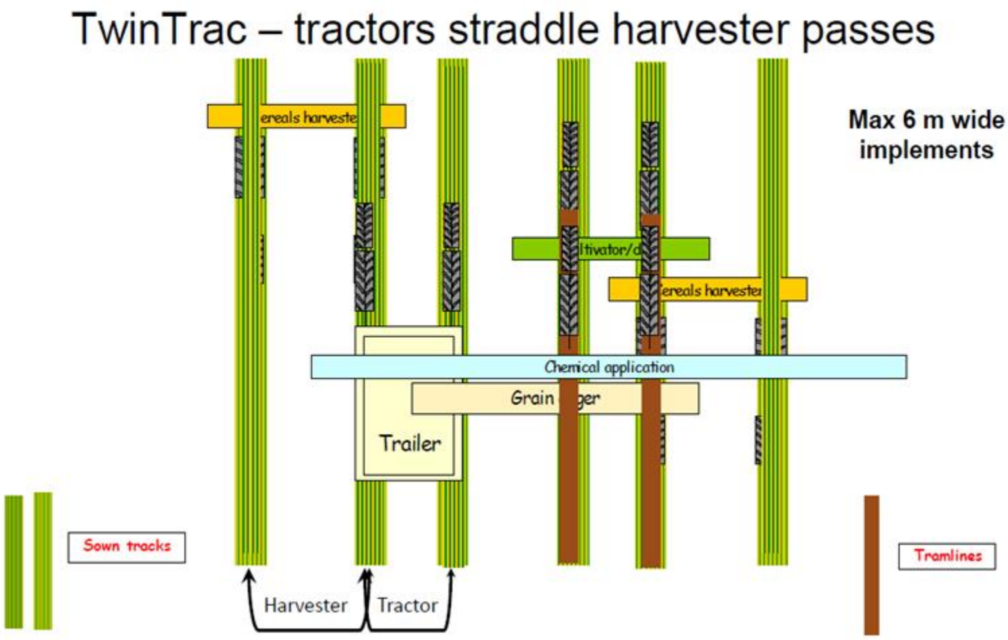


Figure 2. "Twin Track" CTF track pattern (Chamen 2006).

Therefore the trafficked area was larger than reported from "ideal" systems like in Australia (11% with a 9 m system width). The un-trafficked area varied at the three locations between 58% and 70% (Figures 3-5).

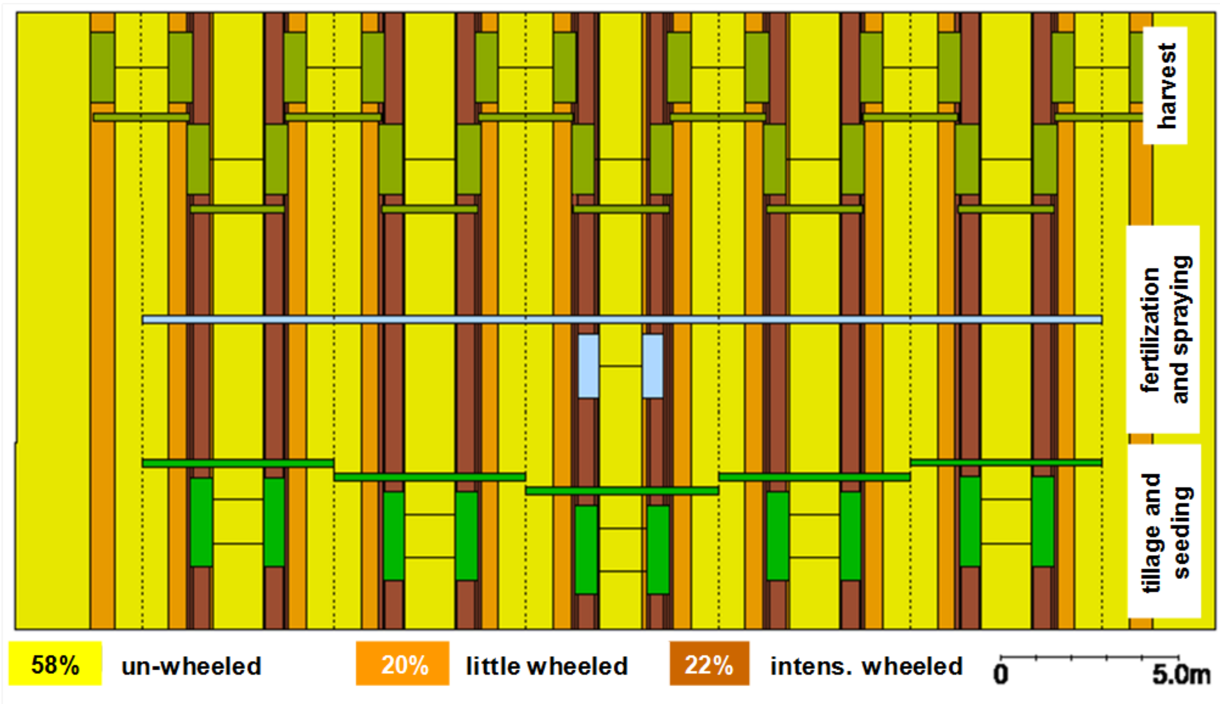


Figure 3. Traffic pattern of farm 1 with 5.4 m system width (sugar beet harvest 2.7 m).

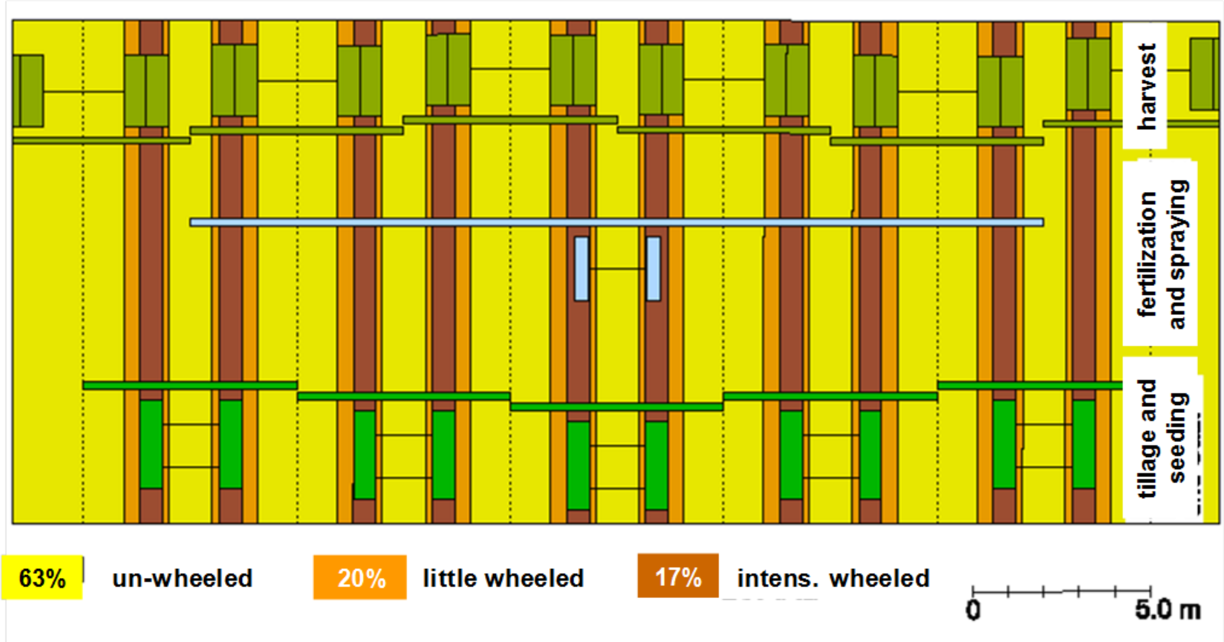


Figure 4. Traffic pattern of farm 2 with 6.0 m system width (combine on duals).

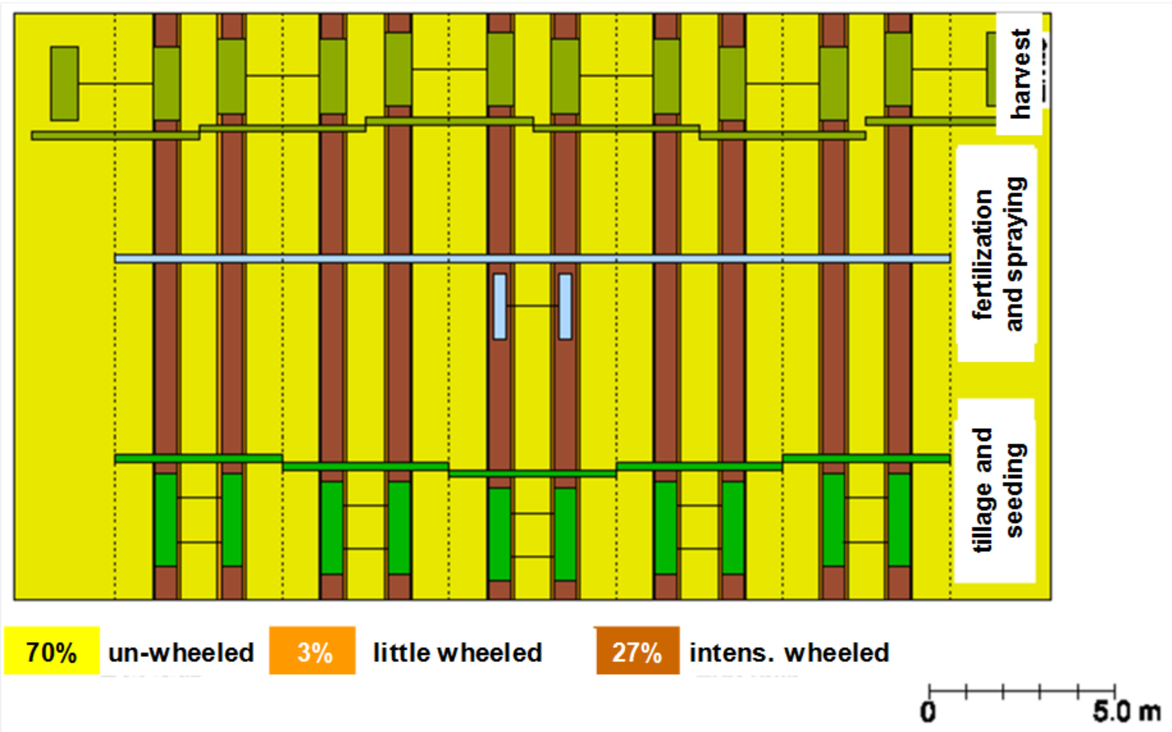


Figure 5. Traffic pattern of farm 3 with 4.5 m system width.

All machines have been equipped with "low ground pressure tires" or rubber belt undercarriages. The combine harvester on farm 2 was equipped with dual tires. Therefore it was possible to enable adequate plant growth also in the tracks (not in the tram lines for fertilization and spraying).

In cereals and oil seed rape (combinable crops) the real traffic pattern was identical to the theoretically planned pattern. Due to technical restrictions and problems (unloading and transfer belt of the sugar beet harvester was to short, track width of the different tractors and trailers for the in-field beet transport has not been identical) the real traffic pattern (GPS monitored) in farm 1 in the year with sugar beets showed a higher portion of wheeled and therefore a smaller portion of un-wheeled (24%) area (Figure 6).

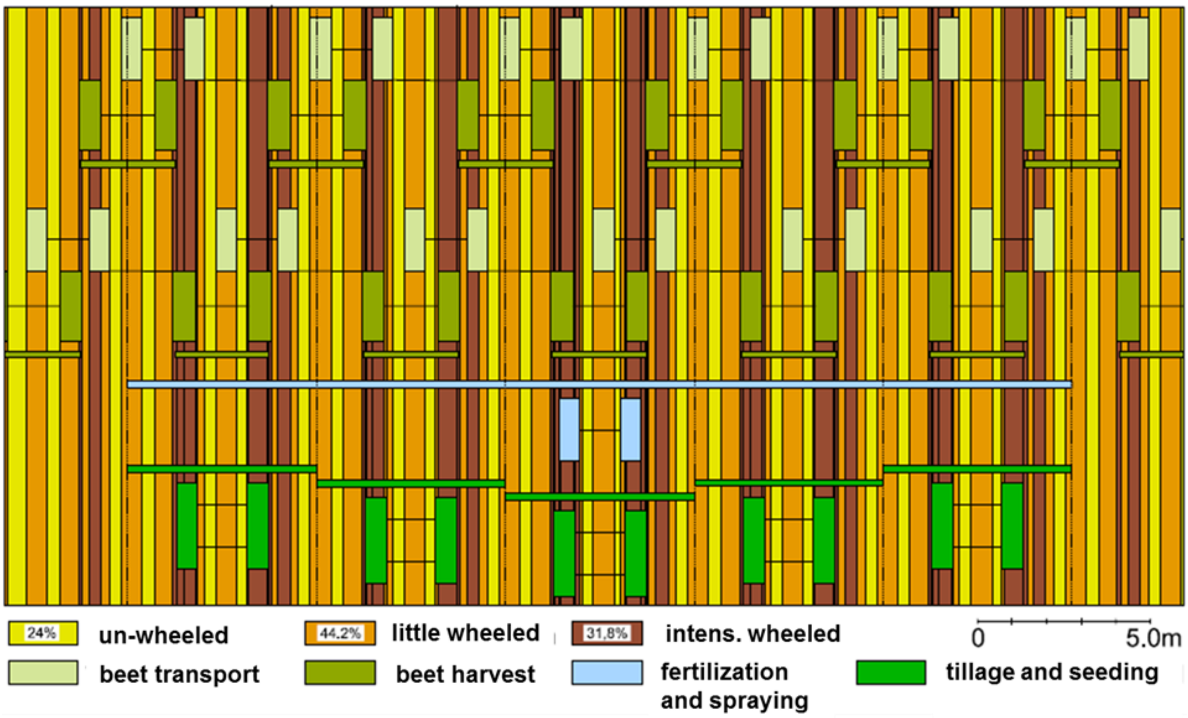


Figure 6. Real traffic pattern (GPS monitored) of farm 1 with 5.4/2.7 m system width in the year with sugar beet

During the 5 years period the investigations showed that it is possible to realize CTF with some compromises also under German (resp. Bavarian) conditions with strict road transport regulations which avoid the use of one common track width. Also the matching of working width was possible, but in the moment system widths of 9 and 12 m turn up to be impossible. There is also no mechanization available to realize sugar beet harvesting with an acceptable un-wheeled area today. Critical is the integration of contractor work due to the compatibility of working width of implements, track widths and guidance systems and the needed understanding of and discipline to work in a CTF system.

3.2. Effects on soil physical properties

Soil physical properties have been analyzed collecting core samples in 2010/2011 and in 2013/2014. Six profiles have been cut per field and per wheeling situation and six ring core samples have been taken per profile and per depth. Core samples have been analyzed for bulk density, total pore volume, air filled pores and water permeability in the soil lab. Figure 7 shows the typical results of the analyses of air capacity in 4 depths on farm 1 in autumn 2013 after the harvest of winter wheat.

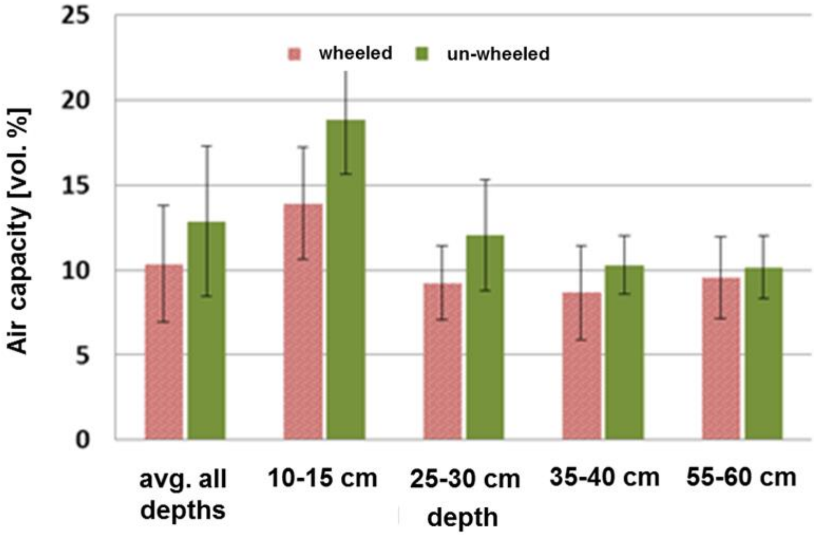


Figure 7. Air capacity in wheeled and un-wheeled areas in 4 depths at farm 1, autumn 2013 after winter wheat (six profiles with six soil cones per depth per wheeling situation).

At the end of the investigation bulk density of the un-wheeled areas was lower than in the wheeled areas in every field. Consequentially the portion of fast draining pores (coarse pores), the relative air capacity and the infiltration rate was higher in un-wheeled than in wheeled areas.

Due to the fact that on farm 1 in sugar beet during harvest nearly the whole field was trafficked, after sugar beet harvesting and in the following season no difference in soil physical properties could be detected between un-wheeled and wheeled areas.

3.3. Effects on soil water balance

Continuously measuring and collecting soil moisture data on 5 fields with 2 x 3 measurement locations in 3 depths in each field was a real challenge. Problems occurred by interrupted energy supply, disturbed data transfer, faulted connections between sensors and data loggers and by lightning. But in the last two years uninterrupted data rows could be recorded. Unfortunately they did not proof the expectations based on the determined differentiation in soil physical properties.

The example shown below showed very little difference in the development of the volumetric soil moisture in between un-wheeled and wheeled areas in the vegetation period of 2013 (Figure 8, farm 1, winter wheat).

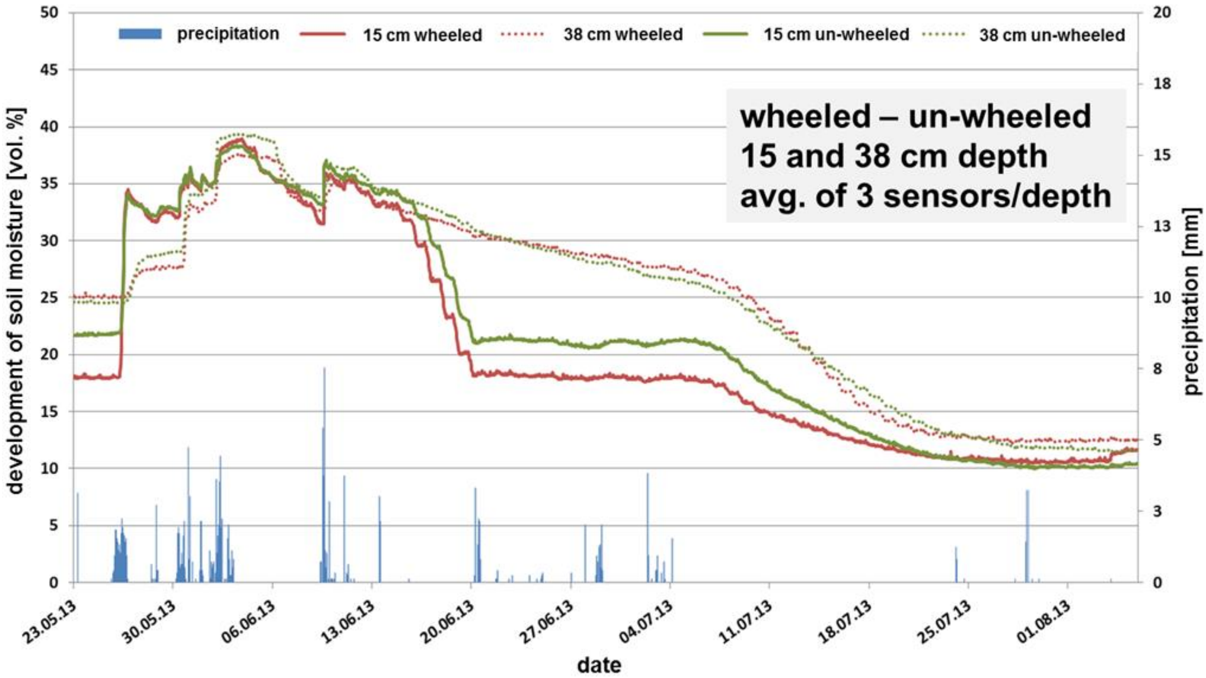


Figure 8. Development of volumetric soil moisture content in 2013 on farm 1 in winter wheat.

The continuous measurement of soil moisture at three locations in every field and in different depth did not show a clear systematic differentiation between un-wheeled and wheeled soils. The expected effects did not show up. Precipitation could infiltrate in the same extend in the wheeled and in the un-wheeled areas. This might be caused by the use of low ground pressure undercarriages on all three farm, the high water capacity of the soils and/or the favorite distribution of precipitation at all three places during the investigations.

3.4. Effects on yields

Yield did not react as clear as soil physical properties and soil moisture tension. Oil seed rape and sugar beets could not be harvested separated between wheeled and un-wheeled areas. The yield reaction of winter wheat and corn was quite different.

In one year on one location significantly higher winter wheat yields were registered in the wheeled areas (farm 2 in 2010). But in general a tendency to slightly higher yields in the un-wheeled areas can be determined (Table 2).

An entirely different reaction of the yield of corn on wheeling could be detected. Due to the fact that in Germany and Western Europe single seed drills for corn (corn planters) have even row numbers (6, 8 or 12 rows), are typically 3 point mounted and the used tractors may not exceed a total width of 2500 mm, the tractor tires are wheeling two of 6 or 8 or 12 rows. In the investigation un-wheeled and wheeled rows on farm 3 have been manually harvested every year and their yields have been compared (Table 3).

Table 2. Absolut winter wheat yields in wheeled and un-wheeled areas of the CTF experiments (average of 10 plots variant$^{-1}$ a$^{-1}$)

| **Culture – location – year** | **yield un-wheeled area [mg ha$^{-1}$]** | **yield wheeled area [mg ha$^{-1}$]** |
|---|---|---|
| winter wheat – farm 2, 2010 | 7.5 | 8.3 |
| winter wheat – farm 1, 2011 | 8.1 | 8.3 |
| winter wheat – farm 3, 2011 | 6.4 | 6.1 |
| winter wheat – farm 1, 2012 | 8.2 | 8.3 |
| winter wheat – farm 2, 2012 | 10.2 | 9.7 |
| winter wheat – farm 3, 2012 | 6.7 | 6.9 |
| winter wheat – farm 1, 2013 | 6.2 | 6.4 |
| winter wheat – farm 2, 2013 | 8.2 | 8.2 |
| winter wheat – farm 3, 2013 | 8.5 | 8.3 |
| winter wheat – farm 1, 2014 | 7.3 | 8.0 |
| winter wheat – farm 3, 2014 | 8.5 | 7.6 |
| ***Average yield*** | ***7.8*** | ***7.8*** |

Table 3. Absolut corn yields in wheeled and un-wheeled areas of the CTF experiments (average of 40 plots variant$^{-1}$ a$^{-1}$)

| **Year** | **yield un-wheeled area [mg ha$^{-1}$]** | **yield wheeled area [mg ha$^{-1}$]** |
|---|---|---|
| 2010 | 10.9 | 9.3 |
| 2011 | 11.3 | 8.4 |
| *2012* | *11.7* | *10.4* |
| 2013 | 7.1 | 6.3 |
| 2014 | 11.4 | 9.8 |
| ***Average yield*** | ***10.5*** | ***8.8*** |

Every year the un-wheeled rows harvested between 11 and 25 % higher yields than the wheeled ones. In average the difference was 16%. This result shows the importance to prevent the wheeling of the area where corn rows will be established.

## 4. Conclusions

Due to legal restrictions it is not possible to harmonize track widths of harvesting equipment and tractors in applying CTF to German resp. Bavarian farms. With standardized system widths between 4.5 m and 6.0 m between 30 and 40 % of the field remains trafficked. Therefore under these conditions this area has to be productive!

The adapted CTF systems could be technically and organizationally realized. Challenges are matching the working width of different equipment, supplying RTK guidance systems to all equipment, and the transfer of track positions between different guidance systems.

Soil structure improved with lower bulk density and higher air capacity in the un-wheeled areas compared to the wheeled areas.

Soil water balance and plant available soil water did not differ between un-wheeled and wheeled areas. It looks like water infiltration was sufficient also in the wheeled areas.

Winter wheat yields did not react on the differences in soil structure between un-wheeled and wheeled areas.

Corn yields clearly and significantly reacted on the differences between un-wheeled and wheeled areas.

The results of the investigation of the soil physical properties and the reaction of crop yields after 5 years of controlled traffic farming under the specific conditions (soils and climate) of three Bavarian locations showed the complexity of soil stress and soil compaction: Under the given conditions winter wheat yields showed no reaction. Due to very little risk of erosion for that culture there is no need or stimulation to introduce CTF. Corn showed positive reaction if growing in un-wheeled soil. Therefore measures should be taken to avoid that corn is planted into wheeled soil. CTF is not generally needed for that. Matching row width, row numbers and track width is the necessary solution, also needed in a CTF system. In future major German resp. Bavarian cash crops should be investigated regarding their specific sensitivity on wheeling / soil compaction to identify in which crops higher investment in systems avoiding random traffic or random wheeling might pay back. Track planning based on geographic information systems and automatic guidance systems is another alternative and pre stage to the “ideal” CTF to minimize the track length in the field and to reduce the area influenced by wheeling.

**Acknowledgements**

The project "Adaptation of tillage systems to climate change", part project "Adaptation, realization and evaluation of controlled traffic farming" was funded by the Bavarian Ministry of Agriculture in the frame of the action plan "Climate Program Bavaria 2020". We also thank the supporting and participating farmers.

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