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Short communication

The evaluation of agricultural machines field trafficking intensity for different soil tillage technologies

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ABSTRACT

Fields trafficking by wheeled farm machines results often in unfavourable soil compaction. In order to monitor trafficking intensity under different soil tillage technologies, every machine was equipped with a DGPS signal receiver before the entrance into the field under conventional, minimum and zero tillage technology. Positioning data was automatically logged every 2 s and the dimensions of tyres (mainly width) and wheel spacing were marked for every machine. Trajectories of farm machines trafficking and wheel tracks covering 1 ha area are shown for different technologies evaluated during one growing season. The results document that up to 95.3% of the total field area was run-over with a machine at least once during a year, when using conventional tillage. Up to 72.8% or 55.7% of the total field area was run-over when using minimum tillage and direct seeding, respectively. It was calculated that 145.6% of covered area can be run-over repeatedly for conventional tillage, 44.8% for minimum tillage and 18.4% only for direct seeding.

1. Introduction

Soil compaction is one of the major problems facing modern agriculture (Hamza and Anderson, 2005). It is mainly related to the intensive exploitation of heavy agriculture machinery. Apart from machinery overuse we find intensive cropping, short crop rotations, intensive grazing and inappropriate soil management leading to soil compaction.

Field soil compaction effects of machines traffic on the fields have been researched in many aspects. Chamen (2006) documented that average weight and power of vehicles used on farms has approximately tripled since 1966 and maximum wheel loads rose by a factor of six. Increased loads enhance subsoil compaction (Håkansson et al., 1987; Arvidsson, 2001) which is mostly irreversible (Horn and Fleige, 2003), and their remediation is very difficult (Berli et al., 2004).

Soil compaction by machinery traffic in agriculture is a well recognised problem in many parts of the world (Chan et al., 2006; Gysi, 2001). Subsoil compaction has been acknowledged by the European Union as a serious form of soil degradation, which is estimated to be responsible for degradation of an area of 33 million ha in Europe (Akker and Canarache, 2001). Moreover, similar problems related to soil compaction have been reported in almost every continent (Australia, Azerbaijan, Japan, Russia, France, China, Ethiopia, New Zealand (Hamza and Anderson, 2005)).

In spite of the fact that compaction is regarded as the most serious environmental problem caused by conventional agriculture, it is very difficult to locate and rationalize it, because marks on the soil surface are not evident (McGarry, 2001).

On the other hand a GPS (global positioning system) receiver as simple equipment of a tractor can be used for detection of areas in the field where multiple trafficking appears. Yule et al. (1999) used a fully instrumented tractor with a global positioning system to map field performance. They demonstrated that the effects of compaction almost doubled tillage costs at the headlands and gateways. Richards (2000) also used the tractor-based global positioning system to map all vehicle movements within a field throughout a complete growing season. He concluded that although there was no major benefit for routine blanket field operations, the system has potential for identifying areas of a field where concentrated wheelings are a problem.

According to Tullberg (1990), trafficking by wheeled farm machines is common in most agricultural operations, even in zero tillage systems. Most, if not all, common farm operations are performed by heavy wheeled machines. Soane et al. (1982) drew attention to the pattern of tractor wheel tracks during traditional seedbed preparations for spring barley in Scotland giving 91% coverage including overlap. It was also reported (Hamza and Anderson, 2005) that over 30% of ground area is trafficked by tyres of heavy machinery even in genuine zero tillage system. Under minimum tillage the percentage is likely to exceed 60% and in

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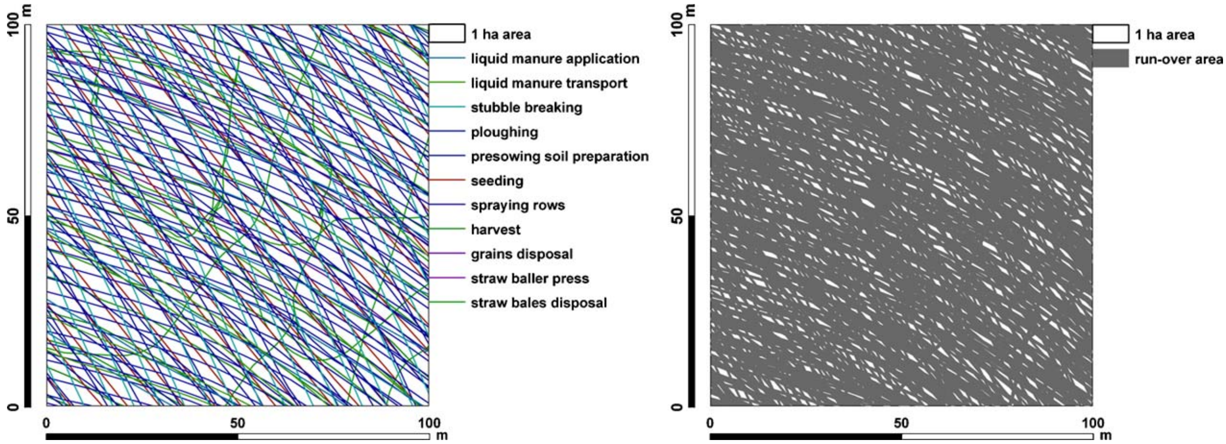

Fig. 1. Graphic representation of machinery passages for conventional soil tillage technology in 1 ha square cut. Left: machines movement trajectories in the field during one cropping season; right: total run-over area.

conventional tillage it would exceed 100% during one cropping cycle. Håkansson (2005) reported estimated traffic intensity in arable fields for some selected field operations and for whole year in various crops for Scandinavian conditions with conventional soil management. For many operations (mouldboard ploughing, chisel ploughing, sowing of cereals by combined drill procedure, sugar beet harvest and some others) wheel track area exceeded 100% of field area. Tullberg et al. (2007) also added that zero tillage reduces the number of operations, but still requires seeding and harvesting, which together apply heavy wheel traffic to app. 50% of field area. According to many authors (Hamza and Anderson, 2005) almost all tyres significantly increase soil compaction in the wheel track and intensity of trafficking plays an important role in soil compaction as deformations can increase with the number of passes (also Botta et al., 2004; Zhang et al., 2006).

Hamza and Anderson (2005) in their review reported that the main source of soil compaction is axle load of farm machinery. They also drew attention to the effects of wheels and tyres and number of passes on soil compaction. Tullberg (2000) demonstrates that the traffic effect on trailed tillage implements can increase total draught by more than 30%. This can be defined as the "traffic penalty" of the operation, and indicates the extent to which a conventional tractor/implement system generates its own workload. "Traffic efficiency" is a parameter proposed to quantify the impact of tractor and implement traffic effects, and used to show that approximately 50% of a tractor's power output can be dissipated in the process of creating and disrupting its own wheel compaction.

It is clear from the literature review that soil compaction as an important factor of soil degradation due to the trafficking of agricultural machines. The percentage of trafficked ground area under different soil tillage technologies is also known. By contrast, only little or no information concerning actual distribution of field trafficking during one cropping cycle is available.

This is why the main aim of our research was to map frequency of machinery passages and to evaluate wheel tracks area under different soil tillage systems during one cropping season.

2. Materials and methods

The methodology of the presented research was quite simple even if time consuming. Two agricultural companies using different soil tillage technologies were chosen for the aim to determinate the frequency of machinery passages, wheel tracks areas and areas multiple-covered by wheel tracks. The technologies used were conventional soil tillage based on ploughing (stubble breaking, ploughing, pre-sowing soil preparation, seeding, etc., see Fig. 1), minimum tillage (stubble breaking, shallow tillage, seeding, etc., see Fig. 2) and zero tillage (direct seeding, spraying, etc., see Fig. 3). Let us note that the organization of trafficking was typical for the technology used in each agricultural company without any intervention from our side.

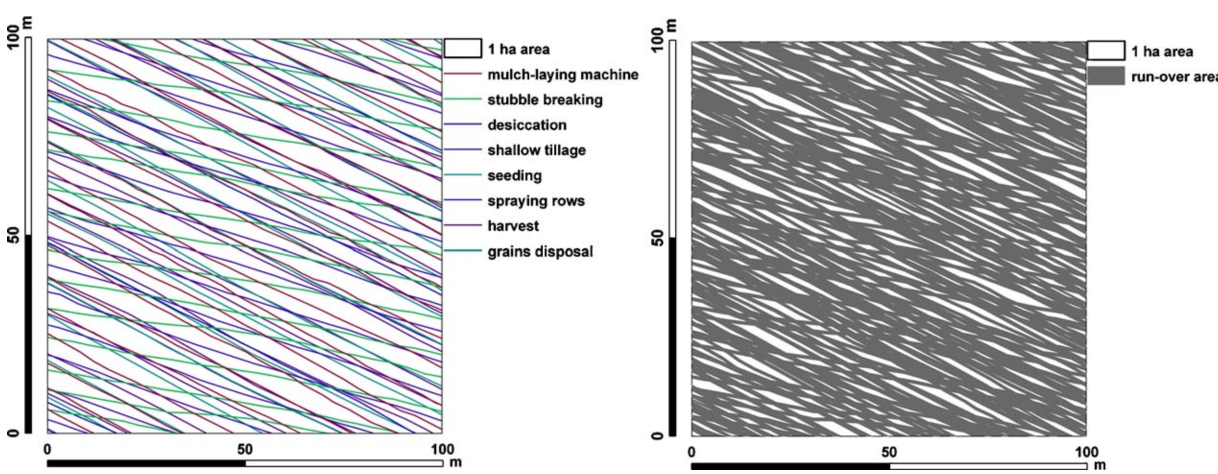

Fig. 2. Graphic representation of machinery passages for minimum tillage technology in 1 ha square cut. Left: machines movement trajectories in the field during one cropping season; right: total run-over area.

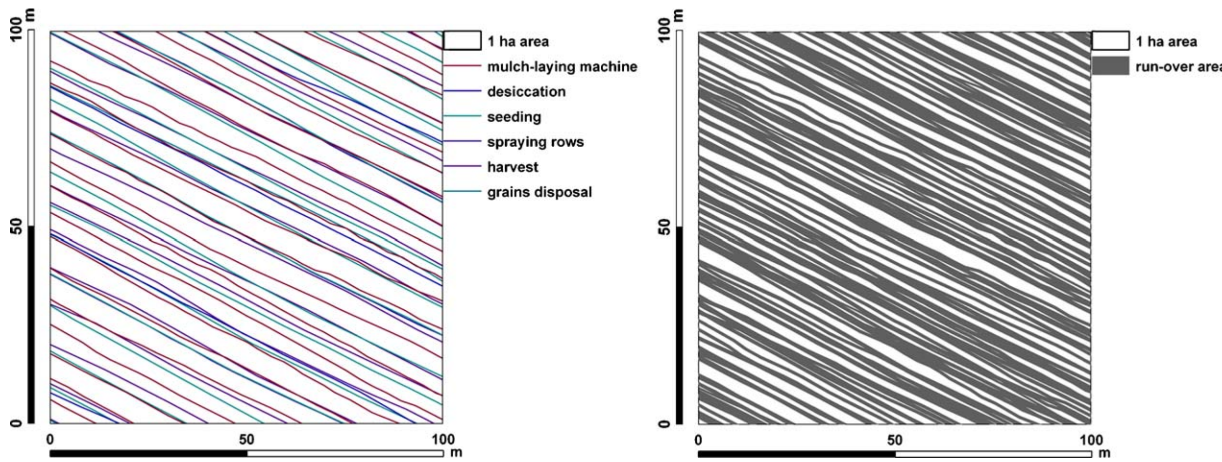

Fig. 3. Graphic representation of machinery passages for zero tillage (direct seeding) technology in 1 ha square cut. Left: machines movement trajectories in the field during one cropping season; right: total run-over area.

The conventional soil tillage and minimum tillage technology represent the main soil tillage technologies in the Czech Republic. On the other hand, direct seeding is a marginal technology only used on about 2% of arable crops area under CR conditions.

The intensity of trafficking was monitored throughout a complete growing season on the fields with different soil tillage technologies used. When in the field, the traffic line (pathway) of every agriculture machine was registered in the time period between the harvests of past crop on the field and the harvest of subsequent crop. A detailed description of in-field machinery operations for each of the technologies evaluated is in Tables 1 and 2.

Every machine was equipped with a DGPS signal receiver before the entrance in the field in order to monitor the trajectory (pathway) of the machine on the field. Positioning data was automatically logged every 2 s and stored in memory of measuring device. The dimensions of tyres (mainly width) and wheel spacing were marked for every machine working in the field.

On the base of data stored we plotted trajectories of machine passages using ArcGis 9.2 SW and consequently wheel tracks areas were calculated in MS Excel. In order to compare the technologies with regard to wheel tracks areas, the values were calculated for a square of 1 ha. Figures with all machines trajectories during one cropping cycle in the field were also plotted for simple visual comparison of the above mentioned technologies.

It is commonly known that the soil water content, soil clay content, etc. can involve soil compaction. Although we were aware of this fact it was just out of the range of this article to observe those influences.

Table 1
Frequency of agricultural machinery passages across a field for conventional soil tillage technology.

Conventional system with ploughing	Operating width (m)	Run-over (%)	Run-over (%)[a]
Stubble breaking	6.0	18.9	37.8
(Liquid manure application[b])	(12.0[b])	(9.1[b])	(9.1[b])
(Liquid manure filling[b])		(5.7[b])	(5.7[b])
Ploughing	10.0	44.6	44.6
Pre-sowing preparation	6.0	32.4	57.0
Seeding	24.0	19.2	38.5
Protection, fertilization (spraying rows)	7.5	2.5	2.5
Harvest		21.7	21.7
Grain disposal		3.9	3.9
Straw balers press		13.5	13.5
Straw bales disposal		6.6	6.6
Run-over (total) (%)		85.4 (87.5[b])	94.5 (95.3[b])
Repeatedly run-over (%)		77.9 (90.9[b])	131.6 (145.6[b])

[a] Dual wheels were used.
[b] Non-typical operations for given technology are included.

3. Results and discussion

The percentage of wheel tracks areas was calculated for different soil tillage technologies evaluated. Particular wheel tracks were drawn on the base of known machine trajectory for given operation and the percentage of wheel tracks area was calculated from 1 ha square cut of the field. The results of those calculations are in Tables 1 and 2. Then, particular wheel tracks areas from all field operations for given soil tillage technology were added together as layers. The result was black area in right side of Figs. 1–3. Resulting area was then expressed as a percentage from 1 ha square cut area (run-over total area, see Tables 1 and 2) as a result from the maps created by ArcGis 9.2 SW.

The areas of run-over appeared repeatedly because the trajectories of different field operations crossed each other. That is why consequently run-over area (see Tables 1 and 2) was also expressed repeatedly. This area was calculated as follows: all percentage values of operation areas (see Tables 1 and 2) were summarized and from that number the run-over (total) area was taken away in the way as it was expressed by above mentioned procedure (ArcGis 9.2 SW). The result was then the repeated run-over area (see Tables 1 and 2), it means that the area of the field run-over was repeated twice at minimum.

All the machine trafficking lines were evaluated in the same way. For different soil tillage technologies, basic operations typical for given technology are included (see Tables 1 and 2). In addition to it there are values in brackets in both tables. These values represent operations not typical for the technology evaluated, but which were performed during the observed cropping season and therefore also evaluated. This concerns mainly nonrecurring operations or operations forced by unexpected circumstances. An application of liquid manure (slurry) in arable technology or use of mulching machine (extremely lodged stems owing to rain-storms) in minimum tillage and direct seeding technologies are typical examples. These not typical operations are marked by one asterisk in the tables. The use of dual wheels was taken into account for conventional tillage technology only. It is marked by two asterisks in Table 1.

Table 2
Frequency of agricultural machinery passages across a field for conservation tillage technologies.

Minimum tillage	Operating width (m)	Run-over (%)	Zero tillage (direct seeding)	Operating width (m)	Run-over (%)
(Mulch-laying machine[a])	(6.8[a])	(23.5[a])	(Mulch-laying machine[a])	(6.8[a])	(23.5[a])
Stubble breaking	8.0	21.7	Desiccation	36	2.8
Desiccation	36.0	2.8	Seeding	8	20.3
Shallow tillage	8.0	21.8	Protection, fertilization (spraying rows)		
Seeding	8.0	20.3	Harvest	36	2.9
Protection, fertilization (spraying rows)			Grain disposal	9	22.6
Harvest	36.0	2.9			2.0
Grain disposal	9.0	22.6			
		2.0			
Run-over (total) (%)		64.6 (72.8[a])	Run-over (total) (%)		42.3 (55.7[a])
Repeatedly run-over (%)		29.5 (44.8[a])	Repeatedly run-over (%)		8.3 (18.4[a])

[a] Non-typical operations for given technology are included.

As it follows from Table 1, in the case of dual wheels exploitation the specific pressure on the soil can be lower (because of larger contact area between wheel and soil) but by contrast the percentage of wheel track areas is naturally higher (including multiple-covered areas).

In Figs. 1–3 the trajectories of farm machines trafficking (left side of the figure) and wheel tracks covered areas (right side of the figure) in 1 ha square cut field area are shown for different technologies evaluated. These figures underline the results from Tables 1 and 2 and they represent the real situation within the field graphically. It is quite clear from these figures that the worst situation was when conventional soil tillage technology based on mouldboard ploughing was used. Fig. 1 for conventional soil tillage technology was plotted on the base of the results in which dual wheels were not considered.

It underlines also the results of track covered areas calculation shown in Table 1. As anticipated and also reported in the literature (Hamza and Anderson, 2005), conventional tillage was evaluated as the worst soil tillage technology with regard to wheelings concentration. Although this had been anticipated, the first sight at the picture of trajectories in Fig. 1 was a bit striking. On the base of our results it is possible to conclude that wheelings concentration might be one of the main disadvantages of conventional tillage. In our case 87.5% of observed field area was trafficked by tyres of heavy agricultural machines when single wheels were used and 95.3% for dual wheels, which is in good agreement with previous findings (Soane et al., 1982; Håkansson, 2005; Hamza and Anderson, 2005; Tullberg et al., 2007). Moreover, 90.9% (145.6% dual wheels) of the evaluated area was run-over repeatedly.

As for minimum tillage technology the situation was a bit better (see Fig. 2). The figure with trajectories was not so striking. The percentage of the observed field area run-over with a machine at least once during one growing season was 72.8% in this case and 44.8% of covered area was run-over repeatedly. Results obtained were better in comparison with those obtained for conventional tillage. Nevertheless the percentage of the field area not run-over by the machine remained still relatively low.

The best results were obtained for zero tillage technology. In that case 55.7% only of the total field area was run-over, which is the lowest value obtained. The percentage of repeatedly run-over area was 18.4% and from Fig. 3 it is also possible to see that the area in the field not affected by wheel tracking is just considerably higher compared to those previous technologies demonstrated in Fig. 1 or Fig. 2.

On the base of the results presented it could be recommended to use soil tillage technology in which wheel tracks are concentrated to one place. Controlled traffic farming technology might be found as advantageous. According Li et al. (2000), the wheel tracks in a controlled traffic system may occupy 20% of the land, but the losses in this area can be compensated by higher yield. Tullberg et al. (2007) reported that considering common tractor/tyre combinations and common levels of tractive efficiency the field area affected by wheel traffic is usually in the range of 20–35% for controlled traffic.

It is also necessary to take into account the fact that subsoil compaction is a severe problem and the soil amelioration is a long-lasting and difficult procedure (Alakukku et al., 2003) particularly when no remedial tillage is applied. Chan et al. (2006) mentioned that to fully realize the production benefits of controlled traffic for some crops it may be first necessary to remove the underlying compaction generated by previous farming practices. Thus, although direct seeding might look as the appropriate technology, soil compaction tends to be additive from year to year, with little chance of complete recovery. Tullberg et al. (2007) for example reported that farmers attempting zero tillage were often frustrated by problems caused by harvester wheel ruts.

Chamen et al. (2003) reported that the methods to reduce or avoid compaction are reducing stress on the soil by lowering contact pressures, keeping the stresses applied as close to soil as possible, adapting adequate practices and cropping and confirming traffic compaction to narrow sacrificial strips. According Hamza and Anderson (2005) increasing soil porosity is a simple tool of reduction or even elimination of soil compaction. It can be achieved by appropriate application of following techniques: addition of organic matter, controlled traffic, mechanical loosening or selecting appropriate crop rotation. Alakukku et al. (2003) highlighted that it is better to avoid subsoil compaction than to rely on alleviating the compacted structure afterwards. On the base of the results presented in this paper we prefer the use of controlled traffic.

4. Conclusion

Based on our results we recommend to use agricultural machines simply equipped with a DGPS signal receiver as a tool for the evaluation of agricultural machines in-field trafficking intensity. Percentage of ground area trafficked by tyres under different soil tillage technologies can be calculated adding the information about machine tyre dimension and wheel spacing. Maps with agricultural machines trajectories in the field as well as maps of wheel tracks covered areas can be charted. 87.5% of the total field area was run-over with a machine at least once during a year when using conventional tillage, and 72.8% and 55.7% of the total field area were run-over when using minimum tillage and direct seeding, respectively. It was calculated that 90.9% of covered area was run-over repeatedly for conventional tillage, 44.8% for minimum tillage and only 18.4% for direct seeding.

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