Machinery guidance systems analysis concerning pass-to-pass accuracy as a tool for efficient plant production in fields and for soil damage reduction

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ABSTRACT

Machines without satellite navigation in fields have a tendency to pass-to-pass errors, especially unwanted overlaps, resulting in waste of fuel and pesticides, longer working times and also environmental damage. This paper evaluates the accuracy of individual machinery passes in fields. Real pass-to-pass errors (omissions and overlaps) in a field were measured on different tractor-implement units with and without guidance system utilization and a comparison between observed guidance arrangements was made regarding final working accuracy and possible benefits from navigation utilization. Additionally, intensity of machinery passes, and repeated passes on soil, as a possible risk for soil compaction in fields, were monitored. The outcomes from our measurements revealed a statistically significant difference between the total area treated by machinery without any guidance system and machinery using precise guidance systems. Concerning the intensity of traffic in fields, it was found out that more than 86% of the total field area was run-over at least once during one cropping season when using conventional tillage practice. The usage of guidance systems can reduce machinery traffic in field to some extent as well and thus improve soil conditions.

Keywords: precision farming; machinery passes; satellite navigation; traffic intensity; soil compaction

GPS (global positioning system) and satellite guidance systems have become a synonym for precision farming and modern farming systems. Utilization of such equipment represents great benefits concerning precise production inputs, minimizing of machine errors in fields and therefore lower costs for agriculture production. The GPS based means can be also used for gathering important data connected to soil protection farming systems. Machinery traffic monitoring and detailed analysis of machines passes across a field can be a tool for the field area determination which is excessively loaded with tyre contacts. Right the excessive traffic is connected with soil compaction phenomena and its unfavourable effects. Also passes arrangement in fields is usually without any system and random and therefore GPS with a particular traffic system can help soil protection. Furthermore, the angle of machinery trajectories connected to the shape of a field during field operations can significantly affect the number of machinery passes (Galambosova and Rataj 2011).

Several authors such as Debain et al. (2000), Cordesses et al. (2000), Stoll and Kutzbach (2000), Han et al. (2004), Dunn et al. (2006) summarize the following general benefits from the use of guidance systems: reduction in driver fatigue, reduction in costs, increase in productivity, improved work quality, improved safety, less impact on the environment, possibility for work at night and when visibility is poor.

Many different types of guidance systems such as ground-based sensing systems, laser systems,

Supported by the Ministry of Agriculture of the Czech Republic, Project No. QH82191.

vision-based machine guidance systems and satellite navigation systems have been used in navigation of agricultural vehicles. Differential global positioning system (DGPS) technology as an enhanced GPS can provide improved location accuracy, from 15-m nominal GPS accuracy to about 10 cm or even up to 1 cm in case of the best systems using differential signals. GPS navigation has introduced many possibilities for better input management by enabling growers and farmers to apply the right amount of inputs at the right location with acceptable accuracy.

Further problem discussed in the article is the machinery traffic in fields connected with soil compaction which is one of the major problems facing modern agriculture and is a well-recognised problem in many parts of the world (Horn and Fleige 2003, Chan et al. 2006). The extent of the soil compaction problem is unction of soil type and water content and further vehicle weight, speed, ground contact pressure and number of passes, and their interactions with cropping frequency and farming practices (Chamen et al. 2003, Chan et al. 2006, Radford et al. 2007).

Not only heavy machinery but also the intensity of trafficking (number of passes) plays an important role in soil compaction as well, because deformations can increase with the number of passes (Bakker and Davis 1995). Multiple passes of a light tractor can do greater damage than passes of a heavier tractor with fewer passes. The critical number of passes was ten, beyond which advantages from the use of a light tractor were lost (Botta et al. 2002). However, the first pass of a wheel is known to cause a major portion of the total soil compaction (Bakker and Davis 1995). Also another fact has to be stated – soil compacted by machinery tyres is not only a problem for one year or even one season, but undesirable compaction and changed soil structure may be found even after several years.

The soil compaction can be reduced by a certain passes arrangement system. Major changes in the traffic regime (on-land ploughing or minimum or no tillage instead of conventional ploughing, no passage of heavy machinery) are recommended immediately after a field has been subsoiled, otherwise recompaction cannot be avoided (Schäfer-Landefeld et al. 2004).

It seems that the possible tool for soil compaction reduction could be controlled traffic farming (CTF). The use of CTF may minimize or eliminate the need for deep tillage or subsoiling, since CTF is based on maintaining the same wheel lanes for several years. Percentage of wheeled area in a field when using CTF will be considerably lower comparing to current practice.

This work evaluates the working accuracy of agriculture machines during different field operations. Real pass-to-pass errors during field jobs were monitored. Differences between pass-to-pass errors during manual machinery steering without any automated guidance and with using GPS – RTK (real time kinematic) based machinery navigation were analysed. Further, intensity of machinery passes, percentage of wheeled area and repeated passes in fields were monitored when using conventional tillage with ploughing and conservation tillage with randomly organized traffic. And also the same parameters were monitored in fields when fixed machinery tracks were used.

MATERIAL AND METHODS

Evaluation of field job working accuracy – pass-to-pass errors. All experiments were carried out during the years 2009–2012. Firstly, 7 different machinery units with different drivers in fields were evaluated during field operations without using any GPS guidance system. A detailed overview of all experimental arrangements measured and experiment conditions are in Table 1.

The measurements were carried out under normal field conditions in different fields without any obstacles in the line of vision. Measured values of pass-to-pass errors were obtained with the help of a laser rangefinder (accuracy ± 0.002 m declared by manufacturer) by means of the so-called matrix method. The method principle is the measurement of the distance between axes or tyre tracks of two neighbouring passes and is described by Bell (2000). The deviations between the actual working width in the field and the implement design width were calculated.

Secondly, the field job working accuracy was monitored on three machinery units (Table 2) alternately with the navigation using RTK signal and without navigation use. The experiment was carried out on larger fields (acreage more than 35 ha) in order to ensure longer undisturbed passes. Each machinery unit has its driver used to run the machine and utilize RTK navigation during field operations. Data loggers to monitor and save

Table 1. Overview of evaluated machinery concerning pass-to-pass errors (manual steering)

Driver	Machinery unit and working width (m)	Driver experience (year)	Orientation in a filed
1	Tractor Fendt 924, disc tiller Lemken, 6	8	by estimation of a driver
2	Tractor JD 8320, disc tiller Strom, 6	5	by estimation of a driver
3	Tractor Zetor 9540, sprayer HARDI, 18	6	by estimation of a driver
4	Tractor Zetor 10540, sprayer HARDI, 18	13	foam marker
5	Tractor NH TE 88, seeder Accord MT, 6	5	disc marker
6	Tractor Zetor 7245, sprayer TECNOMA, 8	6	tramlines
7	Tractor Zetor 7245, sprayer TECNOMA, 18	6	by estimation of a driver

the data about vehicle trajectory were placed into every machine. The task for the driver was to run approximately 10 passes or to do at least 45 min of field job with and further without navigation use. These two variants were repeated at least 3 times for each machine.

Processing of logged data and graphical visualisation of machinery trajectories was done by means of Statistica Cz 8.0 version (Statsoft, Tulsa, USA) and ArcGIS 9.2 software (Esri, Redlands, CA). The deviations between the performed working width and the implement design width were calculated.

Evaluation of traffic intensity within a field. Evaluation of the number and frequency of agricultural machinery passes across a field was realized by means of DGPS receivers with a position recorder with 2 s logging time.

All machinery and vehicle passes across selected fields were monitored during one year. Conventional tillage with ploughing and conservation tillage system was evaluated. Trajectories for every machine run in the field were defined from the data sets received from the GPS position recorder placed in the machine. Then the area covered by the machine tyres was calculated from the tyre type, tyre width and wheel spacing. This total trafficked area means the sum of ones and repeated wheeled soil surface and was calculated from GIS software tool. For better evaluation and comparison between different tillage systems, 1 ha of a particular field was chosen as a representative square with one 100 m long side when processing the data. Machinery unit trajectories within 1 ha representative square were chosen in the distance of 30 m from the field headlands at minimum. Machinery units have to pass at least 100 m of work in stabilized operation mode.

Last experimental arrangement evaluating the number and frequency of agricultural machinery passes across a field were plots with fixed track system set for machinery traffic (CTF). The measurements were done in CTF fields in exactly the same way as previous random traffic measurements. CTF trials were established and evaluated only for conservation tillage. The CTF experiments were established for two machinery units with working widths 4 m and 8 m.

RESULTS AND DISCUSSION

Evaluation of field job working accuracy – pass-to-pass errors – manual steering. This experiment was carried out for the pass-to-pass error measurements with no guidance use. The best results with the lowest errors performed drivers 1, 2 and 5 probably because of smaller working width (6 m) as opposed to the arrangements with sprayers (18 m). It was evident from the statistical analysis that working width had a significant influ-

Table 2. Overview of evaluated machinery concerning pass-to-pass errors (manual steering versus real time kinematics (RTK) autopilot guidance – accuracy ± 0.025 m)

Driver	Machinery unit	Working width (m)	Treatment	Differential signal type
1	CAT MT765B, Horsch Phantom FG8	8	seed bed preparation	RTK
2	CASE STX 450, Swifter Combi 15000	15	tillage – shallow loosening	RTK
3	JD 8210, Lemken Soliter 10	6	seeding	RTK

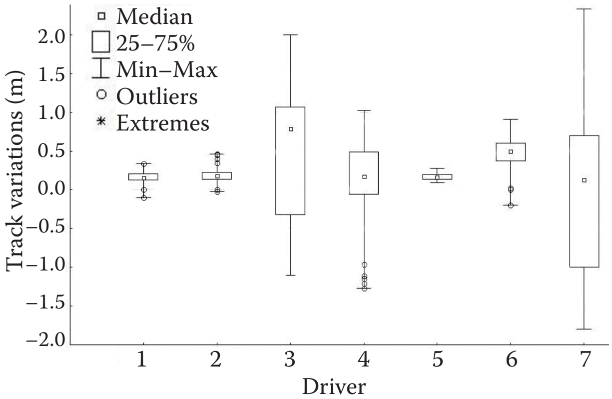

Figure 1. Graphical overview of pass-to-pass errors for machines without guidance system use

ence on the accuracy of field operation. The driver with the tiller was able to continue the next pass more precisely than the one with the sprayer. All the spraying jobs were pre-emergence treatments on soil surface without visible tramlines, except driver 6. The sprayer performed with better accuracy when using foam markers. The best result had the driver 5 during seeding with disc marker. Graphical representation of errors distribution is charted in Figure 1.

Evaluation of field job working accuracy – pass-to-pass errors – RTK navigation versus manual steering. The results when comparing the same machine unit with the same driver alternately with the navigation using RTK signal and without navigation use revealed that the utilization of guidance system gives significant benefits. When machine was operated manually the pass-to-pass errors were obviously bigger than with fully automated steering systems with RTK navigation. The outcome values show prevailing overlaps of passes in the range between 1% and 6% of machine's working width. This value can be significantly minimized by utilization of precise guidance systems, based on RTK signal. The graphical visualisation of the results is in Figure 2.

Evaluation of traffic intensity within a field – random machinery traffic. Different tillage systems were evaluated with regard to the intensity of machinery passes across fields. All machinery entries and movements in the evaluated field during one year were included into the analysis (Table 3). The sequence and frequency of field operations corresponded with real farm conditions and depended only on the farmer decision and common practice. The results showed that 86.14% of the total field area was run over with a machine at least once a year, when using conventional tillage, and 63.75% of the total field area was run-over when using

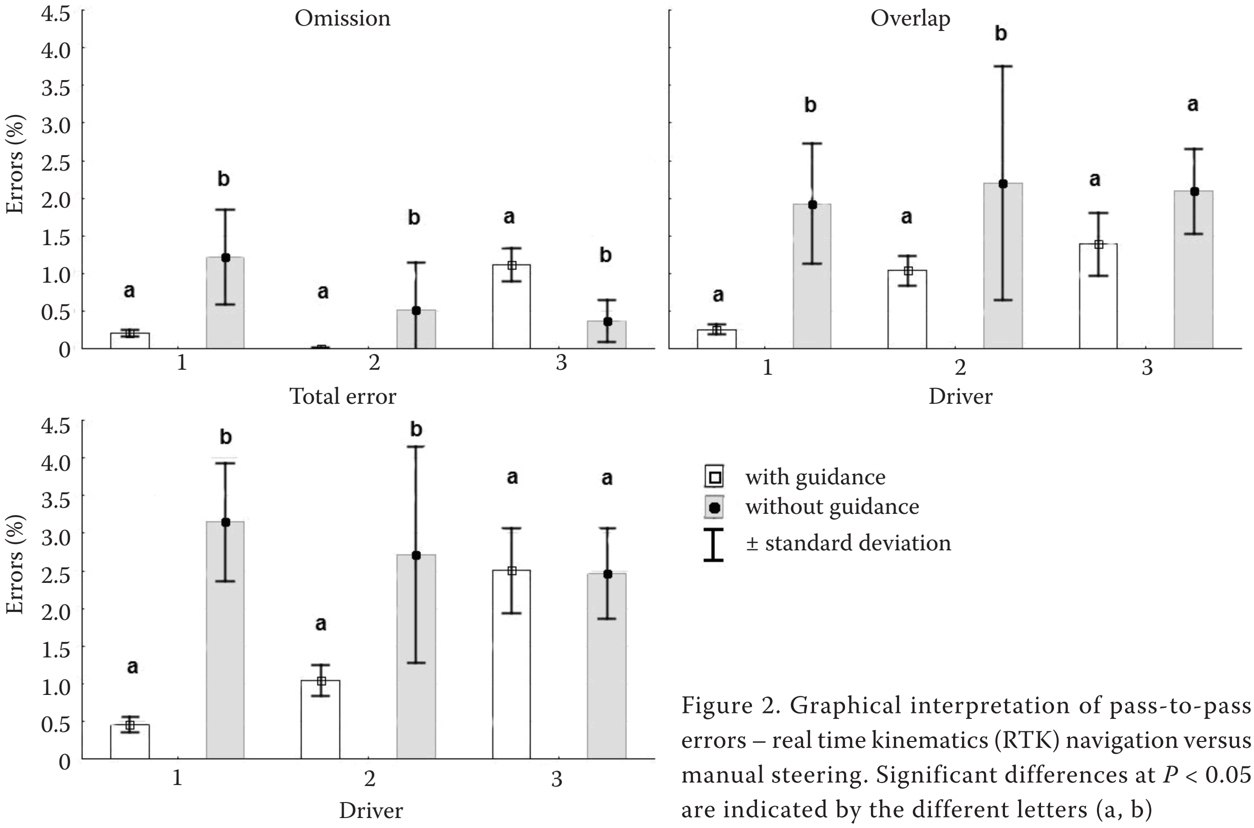

Figure 2. Graphical interpretation of pass-to-pass errors – real time kinematics (RTK) navigation versus manual steering. Significant differences at $P < 0.05$ are indicated by the different letters (a, b)

Table 3. Frequency of agricultural machinery passes across a field

Conventional system with ploughing	Width of tyres (mm)	Working width (m)	Run-over (%)	Conservation tillage	Width of tyres (mm)	Working width (m)	Run-over (%)
Stubble breaking	580	6	18.9	stubble breaking	800	8	23.0
Ploughing	710	3.5	44.6	desiccation	465	36	2.67
Presowing preparation	580	10	32.0	shallow tillage	800	8	21.4
Seeding	580	6	19.2				
Protection, fertilization				seeding	800	8	20.2
(spraying rows)	300	24	2.5	protection,			
Harvest	800	7.5	21.7	fertilization	300	36	2.81
Grain disposal	580		3.9	(spraying rows)	900	9	25.2
Straw ballers press	480		13.5	harvest	710		0.9
Straw bales disposal	460		3.9	grain disposal			
Repeatedly run-over area (%)							
1 ×			33.26				39.26
2 ×			31.06				19.56
3 ×			15.60				4.41
4 ×			5.03				0.51
5 ×			1.04				0.01
6 × and more			0.15				
Run-over (total)			86.14	Run-over (total)			63.75

conservation tillage. Figure 3 shows one example of a position record of a machine collecting bales from the field. Figure 4 shows places with different time exposure of soil to the machinery load. The map was created from the sum of machinery position records in time at a particular place – in the square grid with the cell 6 × 6 m.

Generally all the results show that the less intensity of field operations, the less loading of soil with machinery passes. Table 3 shows the percentage area repeatedly wheeled which causes even worse effect on soil.

Evaluation of traffic intensity within a field – fixed track system for machinery traffic (CTF).

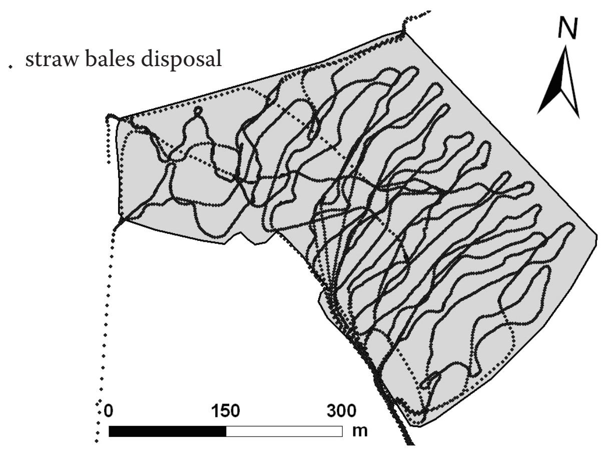

Figure 3. Tractor trajectories from bales disposal – position record

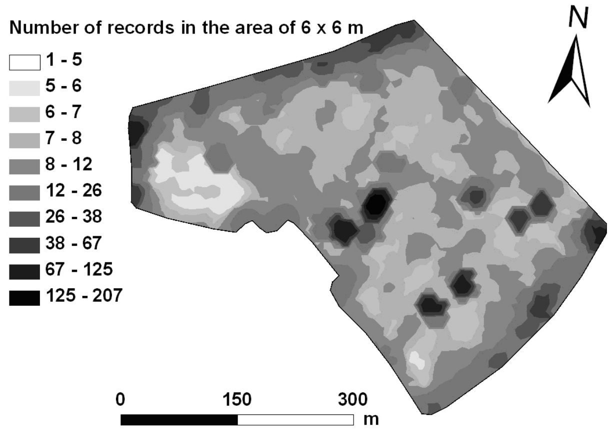

Figure 4. Map characterising intensity of traffic and time spent at a certain area

The experimental plots for CTF trials were treated only like conservation tillage fields. Intensity of wheeled area decreased when using a 4 m fixed track system up to 37% of total run-over area. With a 4 m machinery working width system, it was possible to concentrate all tyre passes into two permanent tracks due to almost the same machine wheel spacing. Generally, the wheel spacing could be the major obstacle for CTF application because there are no standards for agriculture machinery manufacturers and also farmers have different machines with different wheel spacing on farms. The exception is usually a combine harvester with wider wheel spacing than tractors and tools.

The experimental arrangement with 8 m machinery working width was exactly this case. All machine tracks were concentrated into two lanes except the combine harvester. Therefore, the combine harvester passes were organized in the way that one wheel of the harvester ran on the existing fixed lane/track and the second wheel made an additional third track. Finally, three-track systems resulted from this case. Intensity of wheeled area decreased when using an 8 m system with three tracks up to 31% of total run-over area. This value is not much different from the 4 m system (37.38%) when taking into account half the number of passes for the 8 m system. This was caused by the third track made by the combine harvester with wide tyres. On the other hand, it is obvious from the results that repeatedly run-over areas increased in comparison with random traffic. A detailed description is in Table 4. All details concerning machinery, tyres and field operations are listed in Table 3.

Table 4. Frequency of agricultural machinery passes across a field (fixed tracks used)

Conservation tillage			
4 m working width		8 m working width	
Number of passes repetitions	Run-over area (%)	Number of passes repetitions	Run-over area (%)
1	4.58	1	10.38
2	3.24	2	0.00
3	5.18	3	8.46
4	16.51	4	7.65
5	0.16	5	1.36
6	7.71	6	0.76
		7	0.78
		8	0.52
		9	0.46
		10	0.51
Total	37.38		30.88

It also has to be stated that the experiments were done under real running condition on farms with conventional machines not especially suitable for CTF, namely concerning tyres. Tyre sizes for CTF would normally be considerably smaller than those commonly used in practice.

In conclusion, the results from the evaluation of the pass-to-pass errors revealed that the utilization of guidance systems on agricultural machines gives significant benefits. When machine steering was dependent on the driver's manual steering, the pass-to-pass errors were bigger than with fully automated steering systems with RTK navigation. The errors were mainly overlaps of passes in the range between 1–6% of machine's working width. Utilization of precise guidance systems based on RTK signal can be a remarkable source for savings in farming when considering number of field operations during one season.

With regard to the traffic intensity in fields, the results showed a high number of tyre contacts with soil when using conventional ploughing tillage technologies. More than 86% of the total field area was run over in this case. Also, a high number of repeatedly run-over areas were detected there (twice run-over area 31%, three times run-over area 15.6%). Conservation tillage had significantly lower number of machinery passes with a total run-over area of almost 64%. When using the system with fixed tracks for all machinery passes, the total run-over area by machinery tyres decreased significantly up to 31% in comparison to randomized traffic in a field.

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Received on September 18, 2012
Accepted on December 2, 2013

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