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Soil damage reduction and more environmental friendly agriculture by using advanced machinery traffic

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Abstract. Nowadays, the agriculture technologies using guidance systems during field operations are more and more common all around the world. 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. Finally, such errors can be taken as useless additional costs of farming. When utilising satellite guidance for field operations, the pass-to-pass accuracy can be significantly improved and thus it is possible to make the agriculture production more efficient.

The purpose of this paper was to evaluate advantages and real possibilities of using advanced machinery guidance systems with regard to energy consumption and efficiency and also more environmental friendly agricultural operations. Real pass-to-pass errors (omissions and overlaps) in a field were measured on different tractor-implement units with and without guidance system utilization.

The outcomes from our measurements revealed that there is a statistically significant difference between the total area treated by machinery without any guidance system and machinery using precise guidance systems. It means, better accuracy of machinery passes in fields with guidance systems could help with energy and material savings. Namely the fuel, seeding material or chemicals can be saved up to 6% from a single field operation.

Key words: soil compaction, reduction, energy and material efficiency, machinery passes, satellite navigation, traffic intensity.

INTRODUCTION

The GPS (global positioning system) based means can be used with a great advantage for important data gathering during field operations when talking about soil protection farming systems. Nowadays, using of satellite guidance systems is more and more common in agriculture practice and have become a synonym for precision farming and modern farming systems. Utilization of such equipment can be remarkably beneficial concerning minimizing of machine errors in fields, setting precise production inputs, and therefore lower costs for agriculture production. Machinery traffic monitoring and detailed analysis of machines passes across a field can be a tool for the field area determination which is heavily loaded with tyre contacts. Right the field traffic is connected with soil compaction phenomena and its unfavourable effects. Also passes arrangement in fields is usually without any system and therefore random and therefore GPS with a precise traffic system can help soil protection.

During the last two decades much research has been carried out within developing and analyzing GPS based guidance systems. Now, these systems are commercially available from leading tractor brands. In normal operations, the driver operates the vehicle manually during the turning operation in the headland, but in the field the auto guidance takes over. At present, the technology is available to take over the full guidance of the vehicle. This implies not only a release of the drivers work. It also opens a big potential for redesigning the tractor. Due to this, the task for the driver now changes from controlling the driving to taking care of the overall operation performance (Jorgensen 2012).

Several authors such as Dunn et al. (2006), Han et al. (2004), Stoll and Kutzbach (2000), Debain et al. (2000), Cordesses et al. (2000) summarize the following general benefits from the use of guidance systems:

– reduction in driver fatigue: guidance systems reduce the effort associated with maintaining accurate vehicle paths;

– reduction in costs: accuracy is increased by reducing 'skip' (omissions) and 'double-up' (repeated application-overlaps) between neighbouring passes in the field;

– increase in productivity: higher operating speeds are possible;

– improved quality: the driver can focus attention elsewhere to ensure better quality;

– improved safety of work in fields;

– less impact on the environment (reduction of machinery pass frequency, reduction of soil compaction…);

– possibility for work at night and when visibility is poor.

It is possible to use many different types of guidance systems such as ground based sensing systems (Hague et al., 2000), laser systems (Chateau et al., 2000), vision-based machine guidance systems (Debain et al., 2000; Han et al., 2004) and satellite navigation systems (Ehsani et al., 2002; Karimi et al., 2006) in almost all machines used in agriculture. Finally, satellite navigation appears to be the most promising and useful way for agricultural machinery guidance in general. GPS-based navigation systems are the only navigation technologies that have become commercially available for navigation of farm vehicles (Batte and Ehsani 2006). Differential Global Positioning System (DGPS) technology 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. As a result, DGPS technology has made the precision agriculture concept more appealing to the agricultural community (Ehsani et al., 2002).

The accuracy of these systems varies from meters down to even millimeters. This range of accuracy is influenced by two factors. First factor are different means of receiving GPS signal corrections and the second is a degree of steering system automation.

Working accuracy for agriculture should be quite high in the range of centimetres and therefore it is necessary to receive coordinates corrections – necessity for differential signals reception. Concerning guidance systems, there are GPS guidance-aided systems and fully automated or 'hands-free' GPS guidance systems.

Berglund and Buick (2005) also point out that it is necessary to distinguish between two different levels of accuracy called *´Year-to-Year´* and *´Pass-to-Pass´*.

Pass-to-pass accuracy when using satellite navigation depends on many factors. There is a difference between a vehicle with an assisted guidance and fully automated steering. The assisted guidance involves human factor errors because the operator still has to turn the steering wheel according to light-bar indication. When using fully automated steering systems, the human factor is excluded and the driver has only to concentrate on the first run and turns on headlands. Implement response to tractor steering, its direction control, is usually delayed which could be a source of errors. A specific problem case is where the tractor-implement unit is moving on a slope in a field in the direction of the contour lines. The implement behind the tractor does not run in line with the tractor direction. Despite the fact that the tractor can be equipped with a slope compensation system, the implement has always a tendency for turning aside.

Further problem connected with agricultural machinery and its passes across fields is soil compaction. Trafficking by wheeled heavy farm machines is common in most agricultural operations even in zero tillage systems (Tullberg, 1990) therefore the vast majority of arable land is endangered by soil compaction. 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). Also another fact has to be stated, soil compacted by machinery tyres is not only a problem for one year or even one season. Undesirable compaction and changed soil structure may be found even after several years. Compaction of soil by traffic reduces soil infiltration, hydraulic conductivity, porosity and aeration and increases bulk density and impedance for root exploration (Gan-Mor & Clark 2001; Radford et al. 2007). McPhee at al. (1995) stated that up to 30% of tractor engine power can be wasted due to soil compaction which increases pulling force demand by 25%.

Soil compaction can be reduced by a certain passes arrangement system which needs GPS guidance system utilization. One possible tool for soil compaction reduction could be Controlled traffic farming (CTF). The use of the technology named controlled traffic farming (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 (Hadas et al. 1990). Control traffic farming with precisely set tyre tracks could be a tool for minimising of soil compaction risk. Together it means, that GPS utilized in precise traffic arrangement, like for example CTF, is again very important electronic means for better environmental friendly agricultural production and for significant savings for a farmer.

The aim of this paper was to summarize and evaluate advantages and real possibilities of using advanced machinery guidance systems with regard to energy consumption and efficiency and also more environmental friendly agricultural operations. 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 based machinery navigation were analysed.

MATERIAL AND METHODS

Analysis of field operations working accuracy – pass-to-pass errors

Firstly, the most commonly used agricultural machinery units in the Czech Republic with different working widths with different drivers were evaluated during field operations without using any GPS guidance system. The experimental arrangements measured and all the details and experiment conditions are in Table 1.

Table 1. Field operations for pass-to-pass errors analysis (manual steering) – season 2012

Driver	Machinery operation	Operating width	Driver experience	Orientation in a filed
1	soil tillage	6 m	8 years	by estimation of driver
2	soil tillage	6 m	5 years	by estimation of driver
3	plant protection – spraying	18 m	6 years	by estimation of driver
4	plant protection – spraying	18 m	13 years	foam marker
5	seeding	6 m	5 years	disc marker
6	plant protection – spraying	18 m	6 years	tramlines
7	plant protection – spraying	18 m	6 years	by estimation of driver

The measurements were carried out under normal field conditions in a even field without any obstacles in the line of vision. Measured values of pass-to-pass errors were obtained with the help of a laser rangefinder 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 (Beel, 2000). For each experimental run and further statistical evaluation of the pass-to-pass accuracy, 36 values were obtained in the following way. Firstly, 7 adjacent passes with the tractor-implement unit were carried out continuously. These passes were consequently evaluated with regard to their true widths (overlaps or missing areas taken into account and actual operation performed by one single pass was calculated). Distances between tyre tracks of neighbouring passes were measured, with the accuracy of 10 mm, and thus 6 values of actual widths were obtained. Further, another 6 measurements of tyre track distances were carried out farther along the passes (the distance between points of measurement along the pass should be equal to the designed working width of the implement). This procedure was repeated completely six times. It resulted in a square sampling grid with one six-unit (6x working width) long side and it provided 36 measured values.

The deviations between the actual working width in the field and the implement design width were calculated. The method and distance measurement described above must be used directly after the unit's pass when the tyre tracks or other identification marks (for instance tramline marks) are clearly visible.

Secondly, the field operation 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 who was used to operate the machine and utilize RTK navigation during field operations. A very simple equipment to monitor vehicle trajectory was placed into every machine – DGPS receivers and data loggers. The task for the driver was to run approximately 10 passes or to do at least 45 minute his field job with and further without navigation use. These two variants were repeated at least 3 times for each machine.

Table 2. Field operation for pass-to-pass errors analysis (RTK guidance) – season 2012

Driver	Machinery unit	Operating width	Driver experience	Differential signal type
1	seed bed preparation	8 m	4 years	RTK
2	tillage – shallow loosening	15 m	6 years	RTK
3	row seeding	6 m	8 years	RTK

Statistical processing of logged data and graphical visualisation of machinery trajectories was done by means of STATISTICA Cz 8.0 (Statsoft, Tulsa, USA) and ArcGIS 9.2 (Esri, Redlands, CA) software. The deviations between the actual working width in the field and the implement design width were calculated (overlaps or omissions).

RESULTS AND DISCUSSION

Analysis of field operation working accuracy – pass-to-pass errors – manual steering

Table 3 shows a basic statistical overview on deviations for the pass-to-pass error measurements when no guidance system was used during field job. The statistics illustrates the variability of measured values together with maximum and minimum values measured.

Table 3. Statistical analysis of pass-to-pass errors for machines without using any guidance system (values in meters)

(m)	Driver						
	1	2	3	4	5	6	7
Mean	0.17	0.20	0.43	0.09	0.17	0.48	0.02
Median	0.15	0.18	0.79	0.18	0.16	0.50	0.13
Standard Deviation	0.08	0.11	0.94	0.61	0.04	0.22	1.01
Skew	-0.72	0.83	-0.10	-0.87	0.59	-0.70	0.02
Difference min-max	0.44	0.48	3.10	2.29	0.19	1.11	4.13
Minimum	-0.10	-0.02	-1.10	-1.27	0.09	-0.2	-1.8
Maximum	0.34	0.46	2.00	1.02	0.28	0.91	2.33

The best results with the lowest errors (standard deviation) performed drivers 1, 2 and 5 probably because of smaller working width (6 m) as opposed to the arrangements with sprayer (18 m). It is evident from the results that working width has a significant influence 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. The sprayer performed with better accuracy when using foam markers. The best result had the driver 5 during seeding when disc marker use is necessary form the precision of seeding point of view.

Positive mean values of errors indicate that the implement mainly overlapped the preceding pass during the field operation.

Analysis of field operation working accuracy – pass-to-pass errors – RTK navigation versus manual steering

The outcomes from our measurements revealed that there is a statistically significant difference between the total area treated by machinery without any guidance system and machinery using precise guidance systems.

The results from the analysis of the same machine unit with the same driver alternately with the navigation using RTK signal and without navigation use showed that the utilization of guidance system gives significant benefits. Manual operation of the machine and its pass-to-pass errors were obviously bigger than with autonomous (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. Therefore these systems can be a possible way for fuel, chemicals, changeable tool parts and other additional material savings.

The statistical analysis and graphical visualisation of the results is in Table 4.

Table 4. Statistical analysis of pass-to-pass errors – RTK navigation versus manual steering (values in %)

(%)	Driver 1					
	omission		overlap		total error	
Guidance	with	without	with	without	with	without
Mean	0.20	1.22	0.25	1.93	0.46	3.15
Median	0.20	1.14	0.23	2.04	0.42	3.08
Standard Deviation	0.05	0.63	0.07	0.79	0.10	0.79
Skew	0.84	0.96	0.81	0.16	0.94	0.85
Difference min-max	0.20	2.62	0.24	3.16	0.35	3.71
Minimum	0.12	0.36	0.18	0.51	0.34	1.75
Maximum	0.32	2.98	0.41	3.67	0.69	5.45
(%)	Driver 2					
	omission		overlap		total error	
Guidance	with	without	with	without	with	without
Mean	0.00	0.51	1.04	2.20	1.04	2.71
Median	0.00	0.27	1.13	1.87	1.14	2.49
Standard Deviation	0.01	0.64	0.20	1.55	0.20	1.43
Skew	3.49	2.10	-0.63	0.65	-0.63	0.62
Difference min-max	0.05	2.72	0.66	5.71	0.66	4.97
Minimum	0.00	0.00	0.64	0.09	0.64	0.84
Maximum	0.05	2.72	1.30	5.81	1.30	5.81
(%)	Driver 3					
	omission		overlap		total error	
Guidance	with	without	with	without	with	without
Mean	1.11	0.37	1.39	2.09	2.50	2.47
Median	1.07	0.31	1.39	2.17	2.41	2.46
Standard Deviation	0.21	0.28	0.41	0.56	0.56	0.60
Skew	-0.29	1.10	0.17	-0.66	0.12	-1.20
Difference min-max	0.84	0.95	1.65	2.47	2.02	2.42
Minimum	0.61	0.08	0.54	0.67	1.50	0.82
Maximum	1.45	1.03	2.20	3.14	3.53	3.24

The measurements and further analysis of the driver steering without any guidance means show mainly overlaps of passes. Similar outcomes discussed Han et al. (2004) and Dunn et al. (2006) in their papers. The range between 1 and 6% of machine's working width is in accordance with published papers as well. This fact is most important concerning costs and generally inputs for agricultural plant production (savings of fuel, chemicals, changeable tool parts, etc.) and GPS guidance system has a great potential for more environmental friendly and cost-effective agriculture.

CONCLUSIONS

General benefits following from the utilization of guidance systems based on RTK GPS signal such as reduction in costs by reducing repeated applications –overlaps within neighbouring machinery passes in the field were proved.

To summarize the results from the machinery pass-to-pass errors analysis, it is possible to give the following statements. It is evident that the utilization of guidance systems on agricultural machines gives the chance to perform a particular field operation in a more precise way with saving of time and fuel.

When machine steering was dependent on the driver's action (manual steering), the pass-to-pass errors were bigger than with autonomous (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. It means that the field is at the area of overlaps treated uselessly twice which results in additional costs for agriculture production.

The worst results were recorded when the machine was without any guidance and any additional aids (disc markers, foam markers…) and the steering was completely dependent on driver estimation.

Also another outcome can be stated – wider the working width, the worse was the working accuracy. 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.

Taking into account number of field operations per one season – in average 6 entries are necessary for each field on a common farm during one year. According to the results, it means up to 6% of overlaps when evaluating connecting the adjacent passes of agriculture machinery. Therefore it can be stated in a simplified way that up to 36% of total farm acreage is uselessly treated each year as additional costs to one year farm production.

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