BENEFITS OF GPS AGRICULTURAL GUIDANCE FOR SUSTAINABLE AGRICULTURE.

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Abstract

The Global Positioning System (GPS) together with sophisticated machinery guidance systems represents great benefits concerning precise production inputs, minimizing machine errors in the fields and, therefore, lower costs inputs for the agriculture. One of the problems in modern agriculture is soil compaction caused by heavy machinery in the fields. Right the excessive traffic is connected with soil compaction phenomena and its unfavourable effects. Machinery traffic monitoring and detailed analysis of machinery passes across the field can be used as determination of the field areas which are intensively loaded with agricultural traffic. This paper focuses on data obtained from agriculture machinery guidance systems to asses and minimise frequency of agricultural machinery passes across a field and to ensure maximum field job efficiency.

Firstly, traffic intensity on a selection of fields was evaluated. Vehicle passes all of field operations and using range of machinery across selected fields were monitored during one year which resulted in a one year traffic intensity map of the fields. Further different tillage systems, machinery working widths and field jobs were evaluated by an evaluation of the number of vehicle passes across the field. The system with ploughing resulted in 86.1 % of total area covered with wheel passes, while the conservation tillage system showed 63.8 % of the area affected by machinery tyres.

Secondly, the pass-to-pass accuracy with or without the satellite navigation was evaluated. The measured data were obtained from RTK guidance autopilots which are a prerequisite for precise in-field jobs. The results show significant benefits of satellite navigation. Without using the satellite navigation during a field operation, a tendency to passes overlapping was found out.

Overall, the experiments revealed enormous intensity of the agriculture machinery passes, randomly trafficking agricultural fields. The application of GPS machinery guidance was a potential to decrease the number of machinery passes in the fields and can reduce the costs of field jobs.

Introduction

The development of precision farming technologies in the 1990s opened up a new way of thinking about mechanisation for crop care. It introduced a number of concepts, which although not new, brought about a shift in the thinking and management of variability (2). The GPS and satellite guidance systems have become a synonym for precision farming and modern farming systems. Utilization of thus equipment represents great benefits concerning precise production inputs, minimizing of machine errors in the fields and, therefore, lower costs for agriculture production. The GPS based means can be also used for gathering of important data connected to soil conservation farming systems. Several authors, such as Dunn et al. (2006) (11), Han et al. (2004) (15), Stoll and Kutzbach (2000) (25), Debain et al. (2000) (10), Cordesses et al. (2000) (8) 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;
- possibility to work at night and when visibility is poor;
- less impact on the environment (reduction of machinery pass frequency, soil compaction, erosion, runoff, water logging, etc.).

Agricultural machinery passages across the field are inevitable now. They are also associated with many negative impacts on the soil environment. Chamen (2006) (6) stated that average weight and power of vehicles used on farms has approximately triplet since 1966 and maximum wheel loads have risen by a factor of six. The continuing trend towards the use of larger and heavier equipment for field operations increases the risk of compaction damage occurring in subsoil. In many parts of the world soil compaction caused by machinery traffic in agriculture is a well-recognised problem (7; 12). Compaction damage anywhere in the soil system creates problems, but once it extends to the subsoil it is much more difficult and costly to alleviate (24). This is expected to be a common occurrence under the conventional farming systems involving random uncontrolled traffic (7).

A preliminary step in the direction of achieving an increasing operational efficiency is a renewed focus on the usage of advanced systems both in terms of technology and management measures. In terms of the route planning for the agricultural field operations, advanced methods based on combinatorial optimisation of fieldwork patterns have recently been introduced (13). Availability of the satellite navigation systems for agriculture contributes to the development and application of practices leading to higher work efficiency and reduces the negative effects of intensive agriculture. The main aims of thus research are as follows:

i) To evaluate the pass-to-pass errors during manual machinery steering without any automated guidance and with using GPS – RTK based machinery navigation.
ii) To monitor intensity of the machinery passes, percentage of wheeled area and repeated passes in the fields under different tillage treatments and crops.
iii) To generate a model of different field spraying track directions to increase working time efficiency.

Material and Methods

Pass-to-pass errors.

The field job working accuracy was monitored on the five machinery units (Tab. 1) alternatively with the use of navigation supported by RTK signal and without navigation use. In order to ensure longer undisturbed passes the experiment was conducted onlarge fields. Each machinery unit had its driver who operated the machine and utilized RTK navigation during field operations. A very simple equipment to monitor vehicle trajectory was placed into every machine – data loggers were directly connected with the RTK guidance monitor. The task for each driver was to run approximately 10 passes or to do at least 45 minute of his field job with and further without navigation use. These two variants were repeated at least 3 times for each machine.

Table 1 Overview of the evaluated machinery units used in the pass-to-pass error study (manual steering versus steering with RTK guidance).

Driver	Machinery unit	Operating width	Treatment	Differential signal, type of guidance
1	CAT MT765B Horsch Phantom FG8	8 m	seed bed preparation	RTK, autopilot
2	CASE STX 450 Swifter Combi 15000	15 m	tillage – shallow loosening	RTK, autopilot
3	JD 8210 Lemken Soliter 10	6 m	seeding	RTK, autopilot
4	JD 8220 Farmet Kompaktomat 8	8 m	seed bed preparation	RTK, EZ Steer
5	CASE 1170 Amazone EDX 6000-TC	6 m	seeding	RTK, EZ Steer

Evaluation of traffic intensity within the field.

Evaluation of the number and frequency of agricultural machinery passes across a selection of fields was realized by means of DGPS receivers with a position recorder and with 2 s logging time. All field operations and all other machinery and vehicle passes across the selected fields were monitored during one year. The different tillage systems were evaluated, namely: conventional tillage with ploughing and conservation tillage. Trajectories for every machine pass 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 tyre type, tyre width and wheel spacing. For a better evaluation and comparison of different tillage systems, 1 ha of a particular field was chosen as a representative square with one 100 m long side when the data was processed. The organization of field trafficking was typical for the technology used in each agricultural company, data collection did not have any influence on the operations conducted.

Accumulation of passages was also evaluated in the whole field. The intensity of the passages was presented in terms of map, which was created from the sum of machinery position records in time at a particular place – in the selected 6x6 m squares (the field was divided by square grid with the cell 6 m).

In addition, number of passes and the area covered by machine tyres were calculated separately for headlands (25 m wide zones round the field). The area on headlands was expected to be more loaded by machinery passes due to U-turns and high intensity traffic and, which was quantified in this study. Winter wheat was the main crop during the observation.

The intensity of the passages was also monitored and evaluated during the planting of potato with the application of de-stoning technology. Same methods of tractors position measuring and data processing was used.

Same method of passages monitoring was carried out during harvest of forage. In this case, the intensity of passages was evaluated for grass mowing, tedding and harvest with forage wagon.

Route planning

For direction proposals of guidance lines the OptiTrail program was used, provided by Leading Farmers CZ, JSC Company. The software enables for a practical demonstration of the situation how the change of line directions and field shape influence the operational efficiency. The model was designed for 18 m working width sprayer with open loop turns.

MS Office Word, Excel, Access, OptiTrail and ArcGIS 9.2 with its accessories and additional packages were used for further data processing and evaluation of the results. Statistica Cz 8.0 version was used for a detailed statistical analysis.

Results

Evaluation of field job working accuracy – pass-to-pass errors – RTK navigation versus manual steering.

The comparison of the same machine unit with the same driver, alternately with and without the navigation using RTK signal, revealed that the utilization of guidance system gives significant benefits. When the machine was operated manually the pass-to-pass errors were higher than with autonomous (fully automated) steering systems with RTK navigation. The statistical analysis and graphical visualisation of the results are shown in Figure 1. Only in case of one driver (number 3), there was no significant change in the values of total errors with or without navigation utilization. Errors could be minimized by using marker during seeding. Nevertheless, relatively high errors were recorded when navigation was using. Also, higher values of total errors in case of driver 4 were recorded. The type of guidance - assisted steering EZ-Steer system influenced total errors values in this case. System assisted steering EZ-Steer is based on additional stepper electric motor mounted on the steering wheel which controls desired line of machine motion. In comparison with fully automated steering, the assisted steering has slower reaction time to a desired change in direction. The results obtained by driver 4 and 5 were found to be different despite the same system being used. This might be associated with the initial soil surface conditions where operations took place, which was rough furrow (resulting from ploughing) and fine tilth (after seedbed preparation), respectively.

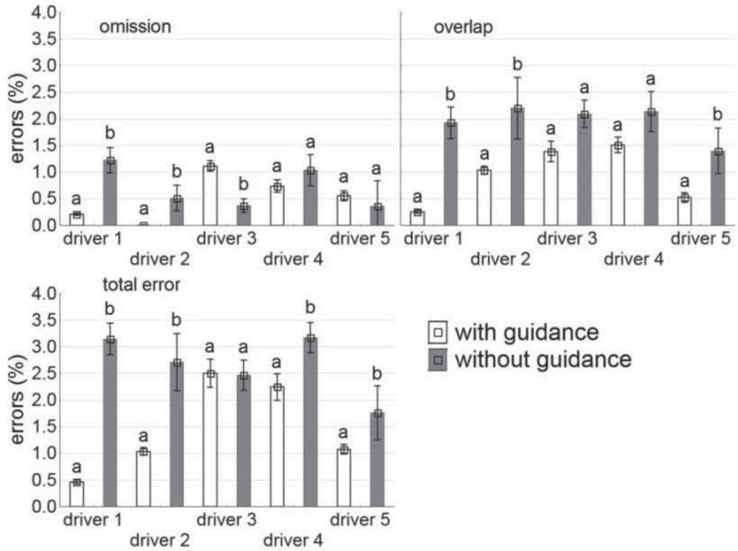

Figure 1 Graphical interpretation of pass-to-pass errors – RTK navigation versus manual steering. Significant differences between pairs of values at $P < 0.05$ are indicated by the different letters (a, b).

Evaluation of traffic intensity within the field – random machinery traffic.

Different tillage systems were evaluated with regard to the intensity of machinery passes across the fields. Tyre tracks and the area ran over by tyres were observed in representative squares selected from each tillage system (area of 1 ha). All machinery entries and movements in the evaluated field during one year were included into the analysis (Table 2) for winter wheat. The sequence and frequency of the field operations corresponded with real farm conditions and was only influenced by the farmer decision and common practice.

Table 2 Frequency of agricultural machinery passes across the field (winter wheat).

Conventional system with ploughing	**Operating width** (m)	**Run-over** (%)	**Conservation tillage**	**Operating width** (m)	**Run-over** (%)
Stubble breaking	6	18.9	Stubble breaking	8	23.0
Ploughing	3.5	44.6	Desiccation	36	2.7
Presowing preparation	10	32.0	Shallow tillage	8	21.4
Seeding	6	19.2			
Protection, fertilization			Seeding	8	20.2
(spraying rows)	24	2.5	Protection, fertilization		
Harvest	7.5	21.7	(spraying rows)	36	2.8
Grain disposal		3.9	Harvest	9	25.2
Straw ballers press		13.5	Grain disposal		0.9
Straw bales disposal		3.9			
Repeatedly run-over (%)					
1x		33.3			39.3
2x		31.1			19.6
3x		15.6			4.4
4x		5.0			0.5
5x		1.0			0.0
6x		0.1			
7x		0.0			
Run-over (total) (%)		**86.1**	Run-over (total) (%)		**63.8**

The results showed that 86.1 % of the total field area was run over with a machine at least once a year, when using conventional tillage and 63.8 % of the total field area was run over when using conservation tillage.

Figure 2 represents machinery pass records from the GPS recorder in the field within the selected 1 ha area (100 x 100 m^2) together with machinery trajectories on 25 m wide headlands. Figures show trajectories of each machinery which ran on the field surface within one cropping season.

Headlands of the field were also evaluated by looking at the repeated passes as presented in Table 3. The results show very intensive traffic and tyre contacts with the soil on headlands, mainly due to the machinery turns.

Despite of the fact that intensity of machinery passes decreased when conservation tillage was used, the loading on the soil profile caused by machinery tyres was still quite high.

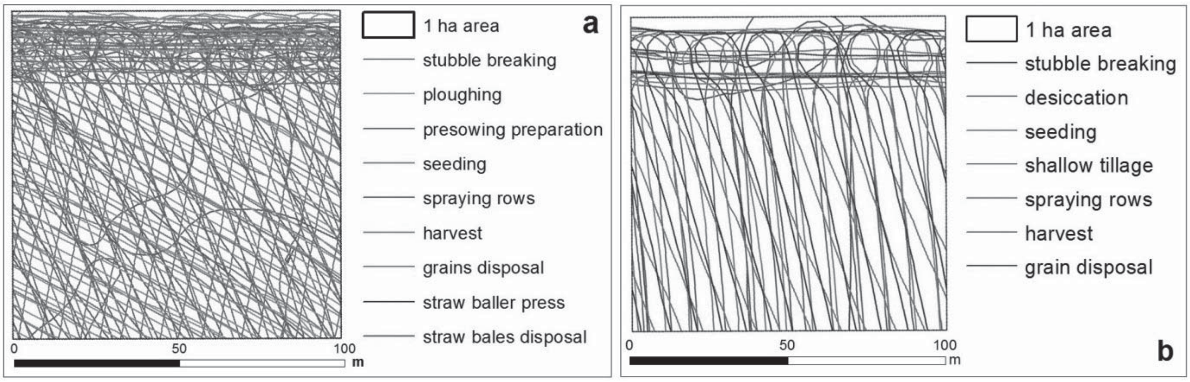

Figure 2 Graphic representation of machinery passages for conventional soil tillage technology (a) and for minimum soil tillage technology (b) on 1 ha square cut (winter wheat).

Table 3 Frequency of agricultural machinery passes on headlands (headland width 25 m, winter wheat)

Conventional system with ploughing	**Run-over** (%)	**Conservation tillage**	**Run-over** (%)
Repeatedly run-over (%)			
1x	17.1		30.2
2x	25.7		31.1
3x	23.9		15.9
4x	15.1		4.1
5x	8.5		0.5
6x	2.9		0.0
7x	0.7		
8x	0.2		
9x	0.0		
10x	0.0		
Run-over (total) (%)	94.1		81.8

Figure 3 shows places with different traffic intensity related to number vehicle passes of soil and time of soil exposure to the machinery loads. It means, the more times a machine entered each square the more records for the square and also the more time a machine spent in the square the more records there as well (dependence on working speed and/or even machine stops).

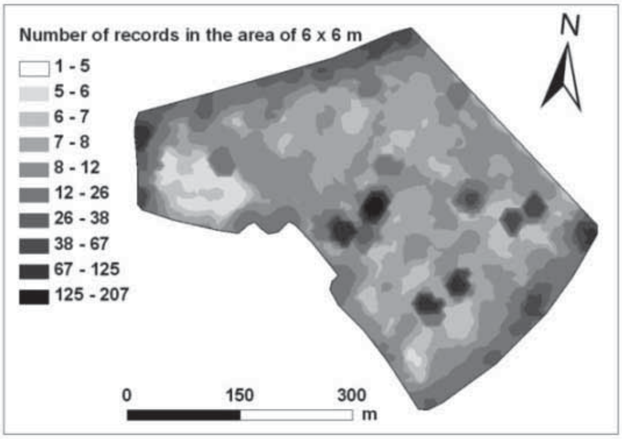

Figure 3 Map characterising intensity of traffic and time spent at the certain area (winter wheat).

Figure 4 shows trajectories of each machine which ran on the field surface within potatoes planting (a) and the real area ran over by all tyres of each machine (b) for a 1 ha square cut. Potato planting is a very intensive technology as the run over area was 84.4 %. In this case, harvesting has not been included yet.

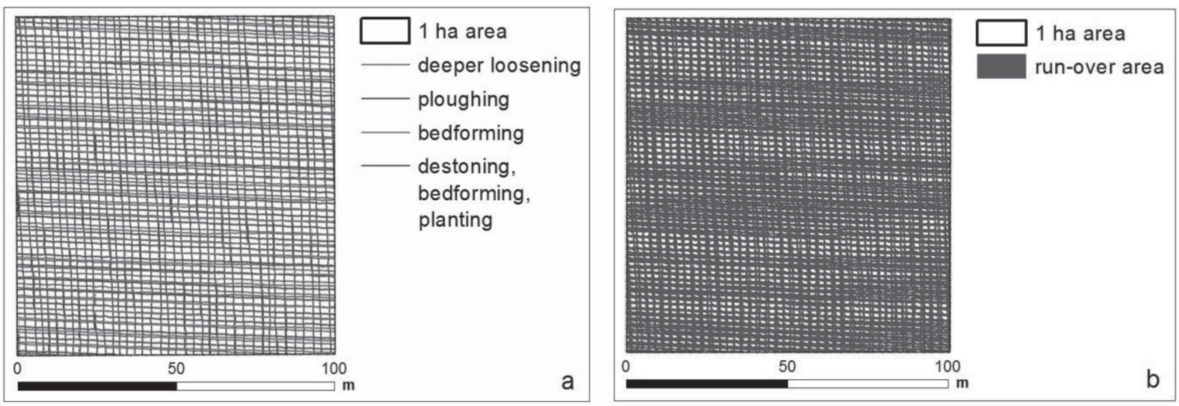

Figure 4 Graphic representation of machinery passages for potatoes planting in 1 ha square cut (a) and total run-over area (b) (potatoes).

It is necessary to highlight, that the intensity of random machinery passes influences not only fields with cereals, oil crops, legumes or potatoes but also grassland or fields with perennial crops. Figure 5 shows all machinery trajectories during harvest of alfalfa field and there is possible to see U-turns with very small radius and passages which can affect crop yields, root system of the plants and soil biota (5).

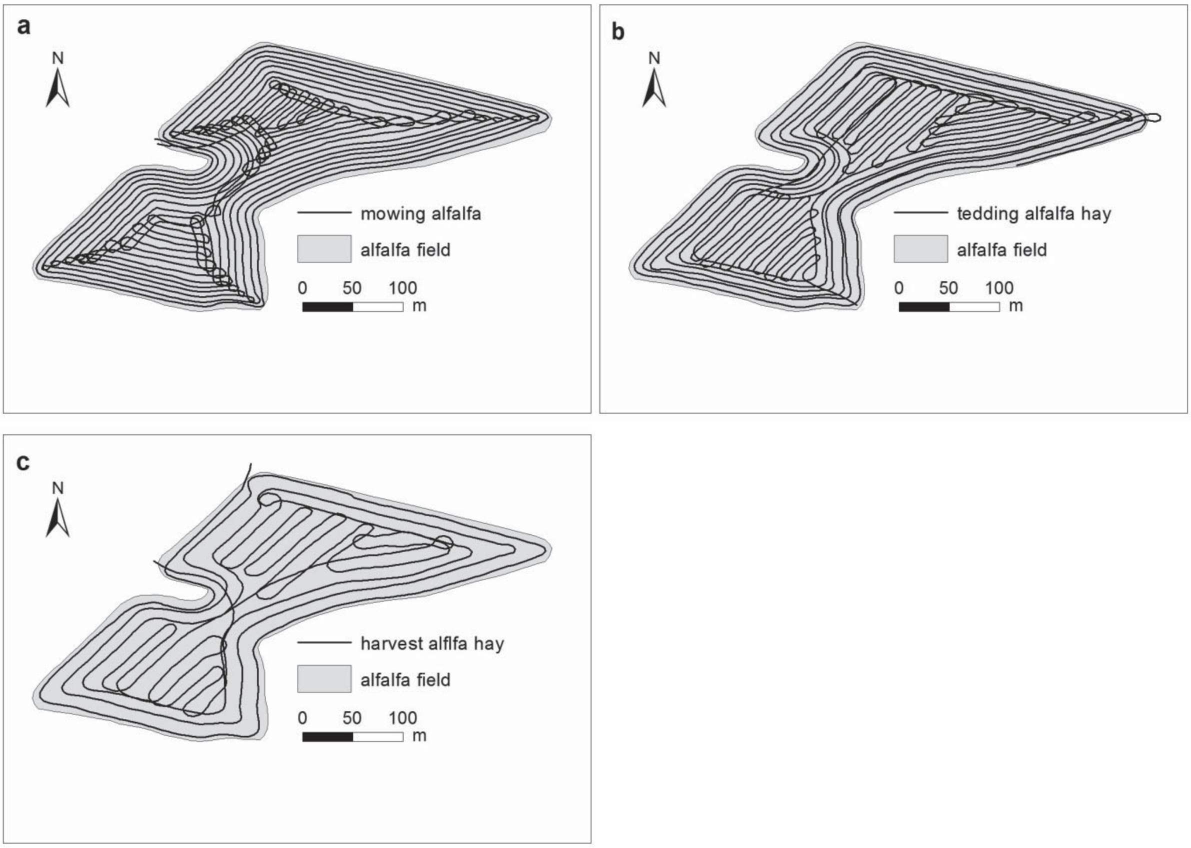

Figure 5 Graphical representation of machinery passes for alfalfa hay field: a- mowing, b – tedding, c – harvest-collection.

Route planning

In terms of immediate practical use and expected benefits of guidance the proposal of guidance lines trajectories is introduced and presented. At present, it is based especially on the experience of drivers or usual habits of farmers. Figure 6a shows an example of an irregular shaped field for which the guidance lines was planned. Figure 6b represents the optimal trajectory which respects the shape of the field and length of the driving distance. The direction of lines graduated at 5° during the modelling. A comparison of the lengths of driving distances for different directions brings Figure 7.

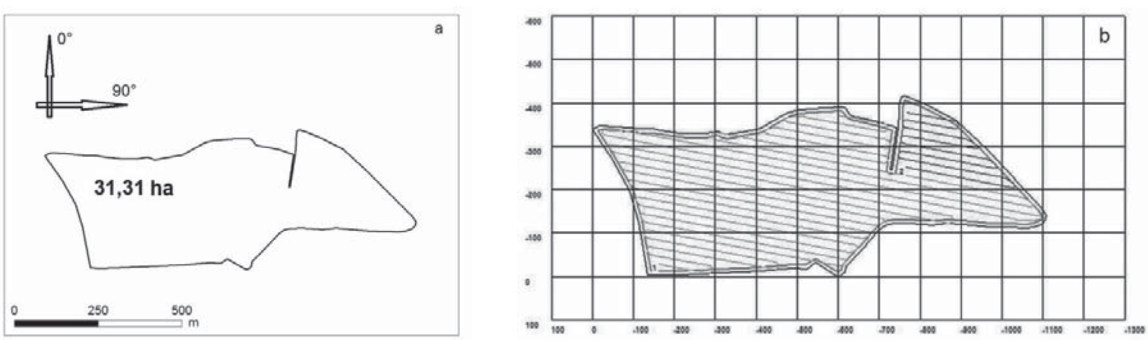

Figure 6 Example of an irregular shaped field for which the guidance lines was planned (a), optimal trajectory of guidance line (b).

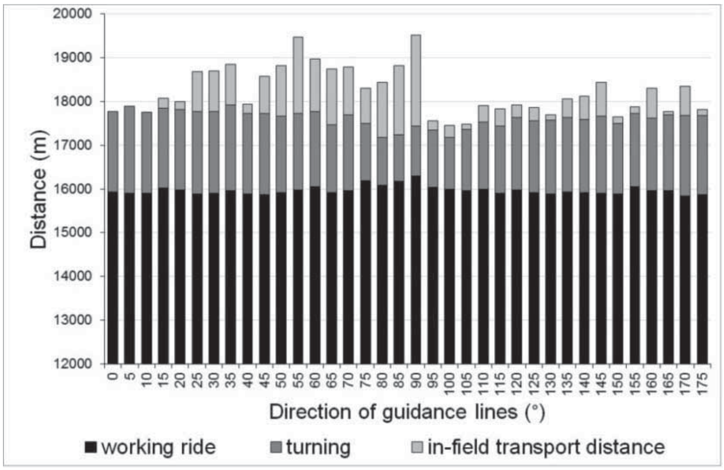

Figure 7 Length of driving distance for the different directions of trajectories.

Discussion

Evaluation of accuracy of field work showed, that the errors can be significantly minimized by utilization of precise guidance systems, based on RTK signal. An application of these systems can potentially result in savings of fuel, chemicals, changeable tool parts and other additional material. Without using the satellite navigation during the field operations, a tendency to overlap was found.

With regards to the number of passes across the field, the results showed a high number of tyre contacts with the soil. It is known from literature that the traffic increasing, represented by the number of passes, produced increasing amounts of the soil compaction and deformation (1; 16; 9; 20). As presented by Botta et al. (2008) (4), reduction of soil tillage intensity results in a decrease in the intensity of trafficking.

The results presented that run over area can be significantly reduced by concentration of passes into the fixed track system. This was proven by the evaluation of conservation tillage which showed that the intensity of wheeled area decreased up to 37% when using a 4 m working width system and up to 31% when 8 m system with three tracks was used (18). The third track was made by a combine harvester with wide tyres. Hamza and Anderson (2005) (14) ant Chan et al. (2006) (7) also presented that reducing the number of passes of farm machinery and confining traffic to certain areas of the field (controlled traffic) are the practical techniques which have emerged on how to avoid, delay or prevent the soil compaction and can lead to more sustainable management. The map of traffic intensity and time spent at a certain area interprets the statement: “Soil compaction phenomenon is connected with number of machinery passes but also with time exposure of soil surface to contact pressure” (1). Monitoring of the machinery passes also brings the possibility of mapping areas of the fields that are repeatedly and intensively loaded by machinery tyres. This information can be then used for planning of remedial tillage treatment against the soil compaction.

Due to the utilization of destoning technology during potatoes planting the elements of fixed tracks system were used. However, the primary tillage operations (deeper loosening and ploughing) were organized randomly and a value of 84.4 % area run over indicates a high level of wheeled area.

The system of passes in harvest and treatment of forage crops also remains random. Meek et al. (1986) (21) presented results of the study, where they determined the influence of traffic and wheel compaction of the soil on alfalfa growth. Meek et al. (1988) (22) further found that the conventional traffic in alfalfa fields reduced yields by 10 % compared to no traffic. Compacting 100 % of the soil surface after each harvest reduced yields even by 17 % compared to no traffic.

The results of Rechel et al. (1990) (23) study show that alfalfa fine roots can grow and develop more intensively within the soil profile which was not affected by wheel traffic and compaction reduces root growth at the different depths depending on the traffic intensity.

In addition to minimize the errors in field trafficking and organize the fixed tracks system, satellite guidance offers other applications, especially, a generations of guidance lines that complement the possibility of increasing the efficiency of the field work. There are also possibilities to combine the fixed tracks system and planning of optimal routes. Landers (2000) (19), Jílek and Podpěra (2005) (17) refer, that there are numerous interwoven factors which affected machine efficiency outputs. The field shape, size, terrain, obstructions and size of the equipment have greatest influence on performing operational steps from the point of view of exploitation, economical and energy criteria. Field, where two sides are not parallel, is adopted as a standard in farm models (19). As Figure 7 showed the minimal deviation from the optimal road may result in significant increase in the proportion of turning and in-field transport distance. Transferring of the optimal road curve to tractor guidance model can be easily applied in the field conditions. Conversely, the model respects only the shape of the land. An important question that remains is slope of the field. The question of erosion risk or tractive performance and efficiency is still not solved. For example Yule et al. (1999) (26) states that the topography and the conditions of the land over which tractor and implement operate exert significant influence upon the machine performance. Substantial weight transferred between drive wheels, especially when operating on steep slopes, can alter the traction and braking. The effect of slope could be explained mainly due to the poorer tractive performance as a result of increased wheel slip. On the other hand, analyses and simulations of operations involving in-field transport, presented by Bochtisa et al. (2010) (3), showed that implementing controlled traffic farming instead of the uncontrolled traffic farming significantly increases the in-field transport distance travelled by an application unit during slurry applications. The outputs from this article showed a necessity for further research and development of organizations of machinery movement on the fields.

Conclusion:

The utilization of guidance systems on agricultural machines gives significant benefits. The results showed that the use of GPS guidance offers a possibility to reduce overlapping and omission which leads to reduction of the run-over area of the field. Recording the machinery position also provides information where the machinery passes are accumulated. The random trafficking results in a high level of agricultural machinery passages across the field, including repeatedly run-over areas. With the application of minimization technology decreases the amount of area that was at least once run-over during the season.

A significant reduction of wheeled area allows adoption of fixed tracks system for machinery traffic (CTF). In this context, the same distance between tractors and combine harvester wheel spacing are recommended, however, it also is possible to use CTF despite of not having all machines with the same wheel spacing.

Combination of fixed tracks system and optimal guidance lines with respect to the shape of the field and its slope may offer an additional increase in the effectiveness of the field work.

In addition, highlight benefits resulting from reduction of errors and minimization of number of non-working passages and transports, it is necessary to refer to the benefits which are difficult to express by specific values as on the minimalization of environmental threats, which are associated with the intensive agricultural.

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