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Spatial overlapping in crop farming works

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Abstract. A good driving accuracy and a proper machine input control are essential in sustainable farming. The goal is to work on the field exactly according to the plan, for example spraying a certain amount of fungicides evenly to the field. However, without modern assisting systems the farmers tend to overlap their driving lines. So far there have not been quantitative tests to present how mark able this overlapping is in real conditions. To solve this, we collected data from regular farming practices during four years in 17 different fields by recording GNSS (Global navigation satellite system) positions and a relative working status of the implement. We developed data mining methods of finding out the average overwork percentages of regular crop farming practices within different complete field plots. Based on the cumulative work distance, we measured the minimum overlapping percentage of different field works. The average minimum overlapping percentages for different machinery were: sprayer 15.7%, combine driller 7.7%, combine harvester 1.7%, spin disk fertilizer 9.5%, cultivator 19% and roller 59%. To understand reasons for great deviation between similar works, we determined different overlapping components for the spraying work: 2/3 of the spraying overlap was because of the driving line inaccuracies while the remaining 1/3 happens in the headland turns. This detected overlapping leads to the over consumption of pesticides, seeds, fertilizers, fuel and time but it can be minimized by applying accurate steering assistance and by adapting automatic section controls.

Key words: GPS, spatial accuracy, steering assistance, section control, data mining.

INTRODUCTION

In traditional crop farming the fields are aimed to be threaded evenly. In irregularly shaped fields this means, that the driver aims to work evenly the entire field, first by circulating the field a few times near field boundaries to produce headlands and then by driving parallel straight lines back and forth. The spatial accuracy of these driving lines is very important: roughly it causes null or double treatments producing unwanted effects. It has been assumed that farmers have a tendency to overlap their work about 10% of the implements width (Nieminen & Sampo 1993; Griffin et al. 2005). Shockley et al. (2011) simulated the overall automatic steering net profits in the farm scale. They assumed that the spraying overlap in unassisted crop farming would be between 1.5 m – 3.0 m, being 9.5% – 19.1% with 16 meter working width. These figures are relatively high in comparison to reported precision farming profits. By using precision nitrogen management for example, the gained overall economic benefits have been at the level of 5% (Nissen, 2012). It is obvious that the effect of overlapping work is very negative to the attempted precision farming acts. Also the overlapping work increases driving distance, takes more time, increases soil compaction, consumes more farming inputs and increases environmental load.

The overlapping work can be reduced by improving the driving accuracy and/or by controlling the implement and its sections more accurately. Different methods for improving the consecutive driving accuracies have now been developed almost a century. Currently, these methods include different track marking devices, using the same tracks (controlled traffic) and using an electronic steering assistance or an automatic steering, typically by applying GNSS positioning based systems. These electronic steering automation methods have widely been developed (Mousazadeh 2013). On top of the improved work quality and increase in productivity, these guidance systems could reduce farming costs, driver's fatigue and impact on the environment and they could improve safety and make it possible to work at night and when visibility is poor (Cordesses et al. 2000; Dunn et al. 2006). The accuracy of these systems is well understood and there are existing standards (ISO 2010; ISO 2012) to produce comparable results. Also these systems have already been adopted by many farmers. However, it is not well known that how much these systems could actually improve the farming results.

Kvíz et al. (2014) found that the regular overlap of passes was in the range between 1% and 6% of machine's working width with drivers who were aware of the test setup. They also found that value can be significantly minimized by utilizing precise guidance systems and the working width had a significant influence on the accuracy of field operation. They measured pass-to-pass deviations with different implements by measuring the distance between the tire tracks of two neighbouring passes with the help of a laser rangefinder by using a matrix method (Bell, 2000). They concentrated on nominally straight driving parts in the field and not measured the headland parts. However, the shape and size of a field significantly affect the number of machinery passes (Galambosova & Rataj, 2011; Oksanen, 2013) complicating the even coverage of the work.

The current problem is that there are no quantitative measures about the unassisted work accuracy in traditional farming in real field conditions. In this study, the unassisted driving means that there are no electronic guidance or steering systems involved. Since 2008, internet based service infrastructure named Cropinfra (Pesonen et al., 2014) has been developed among others to collect and maintain quantitative data from typical Finnish farming practices. Data is collected with GNSS (Global Navigation Satellite System) based measurement systems implemented in all grain farming machines at the research station. This data forms a good source for quantitative analyses. In this study, we developed data mining methods of finding out the average overwork percentages of regular grain farming practices within different complete fields. This overwork amount is practically the minimum overlapping amount in the field. The overlapping work is done by accident and in the optimal case it does not exist at all. Using spatial analyses we also determined the sources of overlapping in spraying works to be able to estimate the positive impact that can be gained with technology adaptation. The research questions of this study are as follows: 1) how much is the average overlapping in regular farming practices? 2) What is the structure of the overlapping and how significant are the different components?

MATERIALS AND METHODS

In this study, we used Cropinfra data from the year 2011 to 2015. For each selected work, we calculated the travelled distance while implement was working. This distance multiplied by the working width was compared with the detected size of the field producing the overwork percentage of the work under the study. This corresponds to a minimum overlapping percentage. These procedures are presented in detail in the following chapters.

Data collection

GNSS positioning, usually GPS positioning is a straight forward way to be used to determine spatial movement. We installed Garmin 19x GNSS receivers in all of the tractors in the test farm. These low-cost NMEA2000 receivers are capable of using GPS, GLONASS and Egnos correction. The measured accuracy in field conditions has been 1.1 metres including a 30 cm standard deviation (Kaivosoja & Linkolehto, 2015). The general drawback of the low cost positioning is the possibility of a position drifting. However, speed detection with a low-cost GPS has been accepted for several studies: Witte & Wilson (2004) studied 1 Hz non-differential GPS for speed determination and concluded that it was accurate enough for biomechanical and energetic studies especially in relatively straight courses. They found that good speed determination was preserved even when the positional data were degraded. Keskin & Say (2006) concluded that low-cost GPS receivers can be confidently used to measure the ground speed in agricultural machinery operations. With the accurate time and speed measurements from the GPS, the travelled distance can be detected.

To determine the work coverage, the implement's working status for each GNSS position was needed. We recorded the status of the implement: power take-off RPM (revolutions per minute) *PTO*, valve status (on/off) *ON*, lifting status sensor voltage (ground level or above) *Lift. V* and the GNSS information simultaneously from the CAN bus with 5 Hz interval (Table 1). All data were recorded from ISOBUS process data messages. All data were synchronized and gathered with developed applications working in LabVIEW environment on a docked laptop.

Table 1. Sample data logging of a spraying work

Time PC	ON	PTO	Lift. V	LAT	LON	Speed	Direction	Elevation
75757.0	0	302	54.8	60.450895	24.346639	1.116	335.07	83.01
75757.2	0	311	54.4	60.450895	24.346639	2.304	335.07	83.01
75757.4	0	317	54.4	60.450895	24.346641	2.808	335.07	83.01
75757.6	1	320	54.8	60.450894	24.346644	2.916	335.07	83.01
75757.8	1	314	54.0	60.450892	24.346646	4.860	335.07	83.01
75758.0	1	317	54.4	60.450890	24.346648	4.680	335.07	83.00
75758.2	1	329	54.8	60.450888	24.346651	4.500	336.93	83.00
75758.4	1	346	54.0	60.450885	24.346653	4.852	338.21	83.00
75758.6	1	361	54.0	60.450883	24.346656	5.304	339.33	83.00

If there were no new GNSS data available, the sensor data would be collected at 2 Hz interval. For those, the speed data was calculated afterwards being the average of five earlier and five later successful speed measurements. If there were over 5 km h^{-1}

deviations between consecutive speed measurements, the speed will be set to be the average of three earlier measurements. Data having less than 0.5 km h^{-1}driving speed was excluded. On average, this method corrected 12 driving speed measurements per each complete field work. The GNSS unit was on top of the tractor. We determined the posture of the implement from the GNSS data and calculated an estimated location of the implement for each record and used that position in our analyses.

We examined only data that did not include any deviances such as work interrupts or log failures due to driver or the system. Based on that, about 1/6 of data were rejected. In total, we evaluated 140 drives driven in 17 different fields. The average size of those fields was 5.3 ha. We used data from a 16-metre sprayer (92 drives), combine driller (22 drives), combine harvester (8 drives) and a roller, a cultivator and a spin disk fertilizer (each six drives) representing a wide scale of farm machinery. We focused on spraying and combine drilling works since those works are often done by avoiding especially gaps but also overlaps.

There were three different drivers producing field data, one having decades of experience, second having nearly a decade experience of farming and the third having about two years of experience. The drivers planned their driving path according to traditional farming practices: work efficiently and evenly the entire field, avoid gaps and overlaps and prefer straight driving lines. The headland drives were used in each work. The spraying and fertilizing drives were matched to earlier sowing tracks if possible. The section control was not used. The cultivating, sowing, rolling and harvesting driving lines were matched to the parallel driving lines.

The driver's awareness of the driving accuracy test could have an effect on the driving result giving too good accuracy results. To minimize the effect, this test setup has been part of our regular field operation practices since 2010 and it has not been related to any accuracy evaluations. First, the farmer turns on the laptop and then starts the logging program from the desktop. Then the driver fills the basic information about the driver, field, machinery and tractor. Then data logging is turned on. While driving, the data logging program indicates that the data logging is progressing successfully. The logging and the laptop are turned off after the task is completed.

To evaluate our findings, we compared one combine drilling work driven with automatic steering system (AGI-4 TopDock) with a cm level positioning accuracy in 2015 to identical work made without steering assistance in 2014. The field plot, the driver and the machine were the same in both cases.

Work amount calculation

After data collection, we calculated the worked area of each work. When the implement status was indicating that the machine was doing work, we calculated the distance based on the detected GNSS speed and time interval. The total worked area was the calculated heading distance multiplied by the known working width of the used implement. We used the working widths that were assumed by the drivers and not concentrated on the detailed machine structure.

There are some challenges on determining the actual field size. There are official field parcel borders in Finland that are annually corrected from digitized ortophotos. These borders define the official size of the field plots; however those polygons do not take into account the surrounding or intra-field ditches so the actual farming size is somewhat smaller. Also many fields are divided into different growing parcels. We defined the actual field area to be the spatial work coverage of the annual sowing work based on our data logging. We calculated the coverage by using a buffer zone method for driving lines (Kaivosoja, 2008), where conscious measurement points forms a vector line. Then for each vector, a surrounding polygon is calculated with the distance corresponding to the working width of the machine. In practice the outer buffer zone line of the headland driving path formed the field boundary.

The sowing data from different years were compared and the biggest area was selected to represent the actual size of the field. The average standard deviation of these buffered areas was 0.03 ha. We used 38 sowing works in total. The determined field sizes were 0.14 ha smaller than the official field polygons in average. The used 17 test fields and single buffered sowing areas are presented in Fig. 1. The fields numbered as 10, 24 and 29 had intra-field ditches.

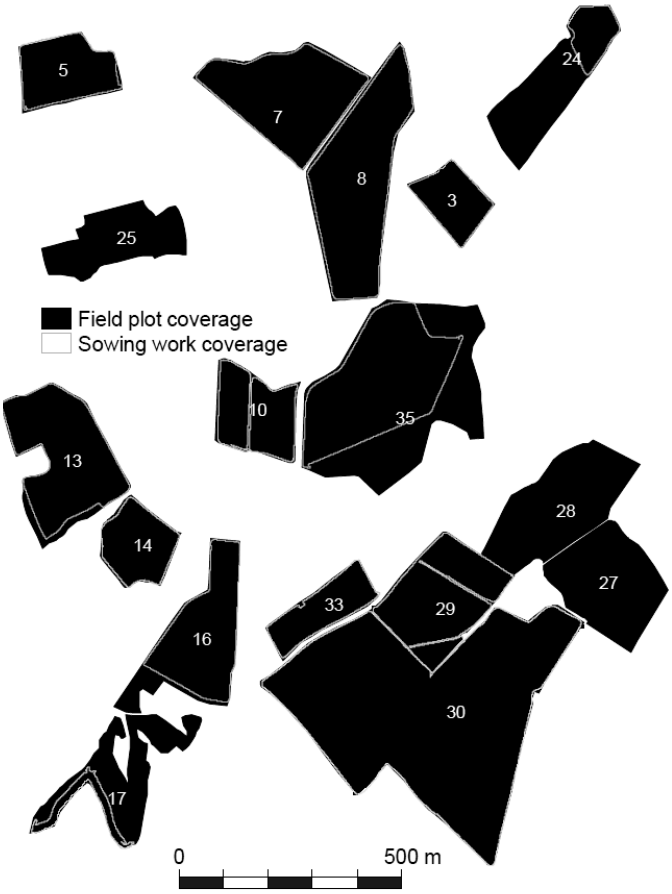

Figure 1. Field parcel borders of the seventeen study fields and the buffered sowing work areas.

The overwork amount of a single work was the total worked area divided by the determined field size. For the statistical analysis of data, we calculated the overwork percentage of each data and then calculated an overall average and the standard deviation of the overwork amount.

Overwork classification

Different overlapping elements for the spraying work were determined to be able to find out the meaning of the determined overwork. We used the buffer zone method to visualise field works (Fig. 2) and to see the characteristics of the overlapping work.

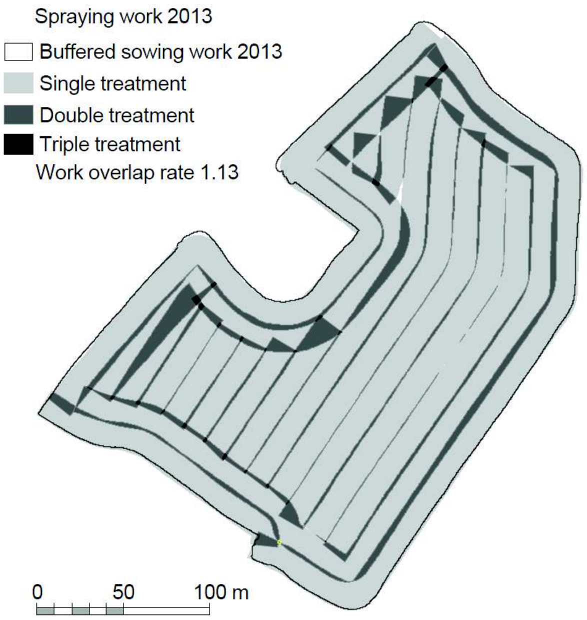

Figure 2. Visualized double and triple overlapping work in the field number 13.

Based on the visual analysis, we evaluated that the detected overwork consist of five main different types of working inaccuracies: 1) overlapping the parallel driving lines, 2) overlapping last driving line, 3) working outside the field boundaries (spraying ditches), 4) overlapping before and after the headland turns, 5) headland overlap because of the gentle enter/exit angle (over 45 degrees). These elements for spraying work are presented in Fig. 3.

We used the following methods to determine the overwork elements (Fig. 3):

1) Overlapping the parallel driving lines: the buffer zone method and the number of passes versus the width of the field.

2) Overlapping last driving line: the length of the last driving line when the machine was working versus the size of the buffered gab between surrounding driving lines.

3) Working outside the field boundaries: buffer zone method to calculate the footprint of the worked area.

4) Overlapping before and after the headland turns: buffer zone calculation for headland drives and the driving distances within that area when machine was working.

5) Headland overlap because of the gentle enter/exit angle: calculate the amount of over 30 degree approaches to headland and using the previously presented method.

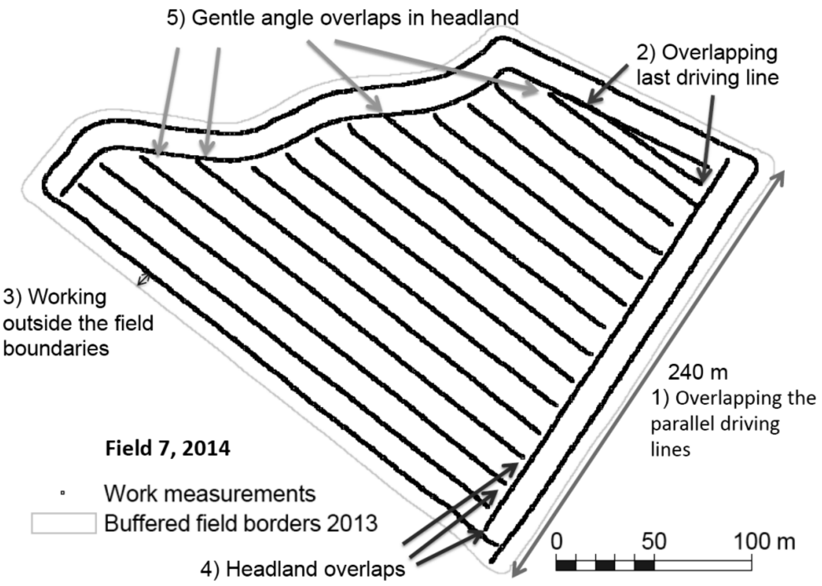

Figure 3. Spraying driving lines and the detected overwork elements.

We adapted the presented methods in order to visually evaluate three different spraying drives (Figs 2, 5 and 6) and made analyses to all of the 17 fields. We used Microimages TNTgis software to map the overlappings, and manually classified the types of overlaps. The software calculated the areas for each overlap.

RESULTS AND DISCUSSION

The selected 92 spraying work drives from four years made in 17 different fields by two experienced drivers result 15.9% overlap on average (Table 2). The overlap rates for different drivers were: most experienced 16.3% (67 drives), other experienced driver 15.5% (14 drives) and rookie 12.7% (13 drives). The rookie's lower overlap rate was due to imprecise work meaning that there were often gaps in the fields. The average standard deviation of all these drives was 9.0%. This was mainly caused while working the headlands. The average overlap of 22 combine driller drives was 7.7% and the standard deviation was 2.1% (Table 2). The measured harvesting work was very close to the sowed area being only 1.7% bigger. The roller and cultivator works produced great overlap with large standard deviation since the nature of the work. The determined overwork of the spin disk fertilization was much smaller than the overwork of the spraying with the equal working width. The following Table 2 shows the details of the used machines, the determined overwork and standard deviation amounts and the measured average overlaps in meters.

Our study revealed that without modern guiding systems, the work overlapping is significant. Each farming work has its own overlapping in different locations. This causes uncertainties to the field knowledge and may greatly weaken the effect of precision farming acts. The measured over consumption of pesticides (16%), seeds (8%) and fertilizers (10%) is significant. The case is similar with fuel and time consumption.

The automatic steering comparison to combine drilling was made in the field plot number 13. The overwork amount in 2014 without automatic steering was 8.3% and with automatic steering in 2015, the overwork was 4.3%. The number of parallel driving line passes was 57 in 2014 and 54 in 2015.

Table 2. Calculated average overwork and the standard deviation of different field works

Machine	Machine type	Width meters	Drives	Overwork %	Std. %	Overlap meters
Hardi Twin Track	Sprayer	16.0	92	**15.7**	9.0	2.54
Junkkari Maestro	Combine driller	4.0	22	**7.7**	2.1	0.31
Sampo Comia	Combine harvester	4.2	8	**1.7**	3.3	0.07
Kire	Roller	5.2	6	**59.1**	13.7	3.07
Amazone BBG Carrier	Cultivator	3.0	6	**19.0**	7.5	0.57
Bögballe DZ Trend	Spin disk fertilizer	16.0	6	**9.5**	8.8	1.52

In the following Fig. 4, the overwork of the spraying and sowing are presented for each field. The X-axis presents the field plot numbers in organized by the field size. In both cases, the entire overwork was overlapping work. There is no direct relation between the size of the field plot and the amount of overlapping. There was only a small correlation between the sowing and spraying overlap in the same fields being 0.51. The difference between the official field area and the buffered field size did not have any correlation with the calculated overwork percentage; this would indicate that our field size determination was successful.

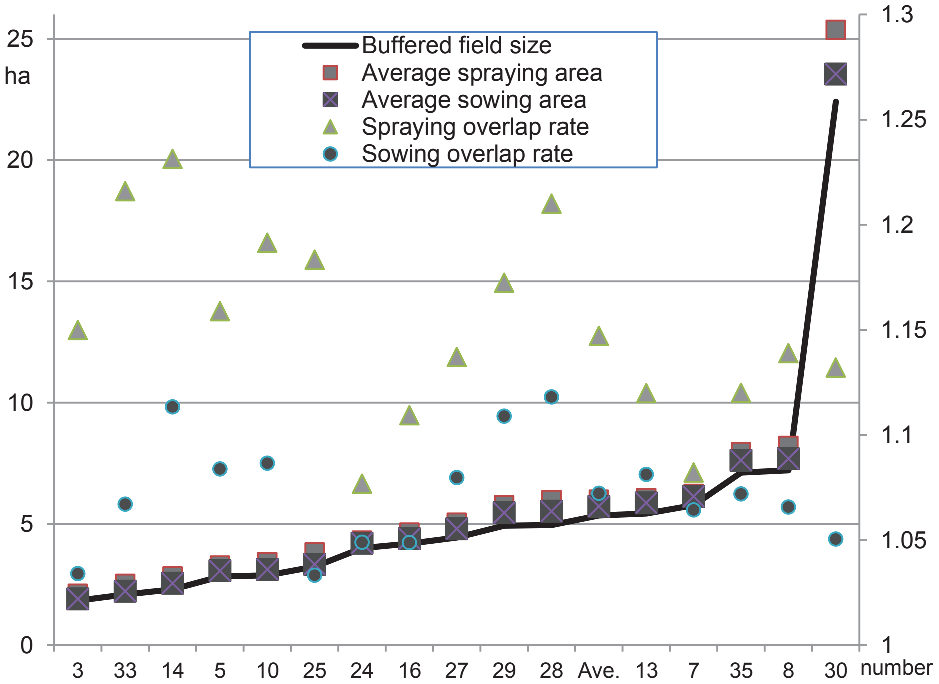

Figure 4. Spraying and sowing work overlap rates compared to field plot size.

Overwork classification results

Our overwork classification studies revealed in that case of field number 13 (Fig. 2), the total 13% overlapping consist of following elements: overlapping the parallel driving lines 8.8%, overlapping last driving line 1.1%, working outside the field boundaries 0.6%, overlapping before and after the headland turns 1.3%, and headland overlap because of the gentle angle 0.8%.

In the following Fig. 5, the different overlapping components are visualized. The dominant grey colour represents successful spraying, all other colours are representing different types of work overlapping. The role of inaccurate headland driving is huge in this small 2.8 ha field causing nearly 15% overlap.

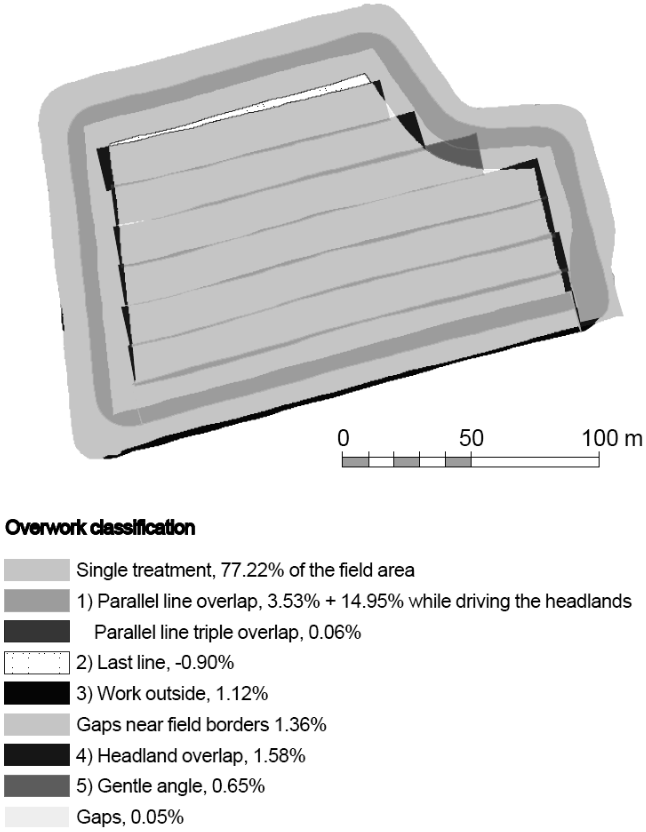

Figure 5. Classified overlapping of the performed spraying work.

The role of headland driving is smaller with bigger fields (Fig 6.) but there are still many different sources for inaccurate spraying work. In this field, relatively great amount of overlapping was caused due to inaccurate section control in each pass causing a 3.4% overlap. Pass-to-pass overlapping in the middle of the field was less than 5% being 75 cm in practice.

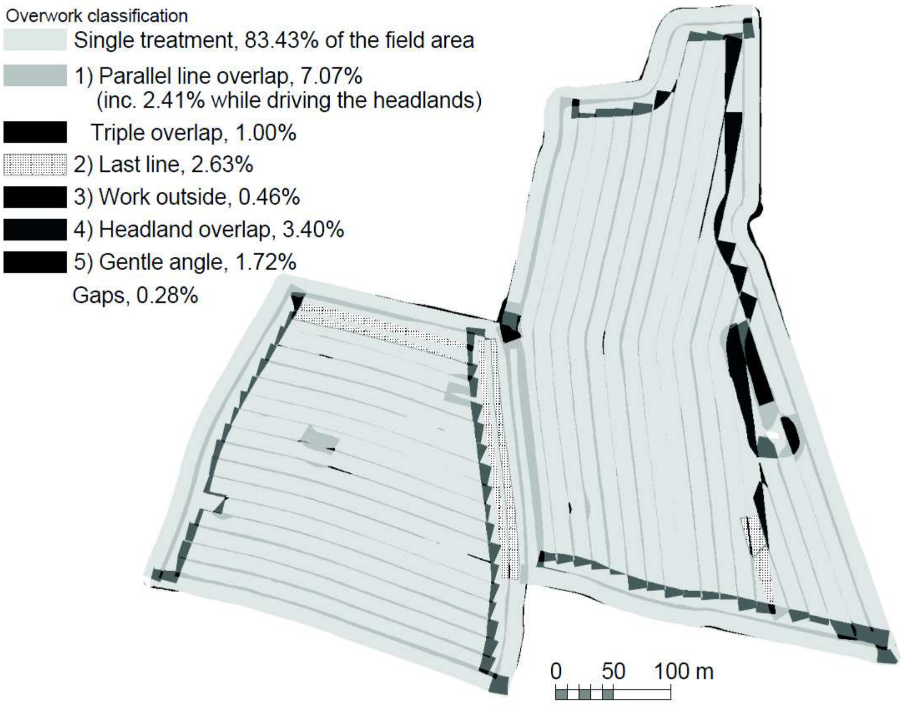

Figure 6. Classified spraying overlap on a large field.

Different overlapping classes for spraying are shown in Table 3 for the presented fields 5, 13, 30 and on average for all the 17 fields. The *OK* class in Table 3 presents the area that got a single treatment according to the plan. The inaccurate parallel driving caused 10.3% overlap on average in the spraying while the headland overlapping was less than 2%.

Table 3. Classified overlapping types in different fields

		Overlap class						
Field No.	Size (ha)	OK (%)	**1** (%)	**2** (%)	**3** (%)	**4** (%)	**5** (%)	Gaps (%)
5	2.8	77.6	18.5	-0.9	-0.2	1.6	0.7	0.1
13	5.4	88.5	8.8	1.1	0.0	1.3	0.8	0.0
30	22.4	83.4	8.1	2.6	0.5	3.4	1.7	0.1
17 fields ave.	**5.4**	**85.3**	**10.1**	**1.4**	**0.0**	**1.7**	**1.4**	**0.0**

In practice, the overlapping happens because the drivers want to avoid gaps that can easily be seen, the irregularly shaped fields are impossible to threaten evenly with big machinery, and the edges of headland areas are often difficult to be seen.

This determined overlapping can be minimized by applying accurate steering assistance and by adapting automatic section control. A plain steering assistance with 15 cm pass-to-pass accuracy would decrease the overall spraying work overlapping amount from 15% to about 7%. Depending on the mapping capabilities, it might also reduce the overlapping in headland turns. According to our automatic steering test, the overlapping in combine drilling work decreased from 8.3% to 4.3%. In practice, this decrease meant 54 kg of seeds and 77 kg of fertilizers, saving about 10 € per hectare with the current market prises.

The assumption that farmers tend overlap their work about 10% of the implements width matched very well to our finding of the spraying line overlapping of 10.3%. This value included the overlapping while driving the headlands and overlapping caused by obstacles in the field. When comparing with Kvíz et al. (2014) who found that the regular overlap of passes was in the range between 1% and 6%, we got bigger values. However, when focusing only our pass-to-pass spraying accuracy in the middle of the field (Fig. 5. and Fig. 6.) we got similar values: 3.53% and 4.66%. This would indicate that using steering automation only in the middle of the field would not significantly reduce the overlap amount.

With better positioning systems and shaft angle measurements the overlapping measurements would have been more reliable in relation to individual fields. By focusing on the driving distance measurements and the averaging, we fairly managed to overcome this drawback. We were focusing on the sowing and spraying and those works are commonly done by avoiding gaps. The overlapping with spin disk fertilization was almost half compared with the spraying. This could happen because the driver is not trying to avoid the gaps more than the overlapping.

The shapes of the test fields were not very regular but they were typical Finnish fields. When comparing the fields with the highest and the lowest amount of overlapping, it is very difficult to draw any conclusion based on field sizes and shapes. Also the high standard deviations of the overwork percentages with different machines are indicating that the overworking is not always happening in the same way. This can also be seen in Figs 5 and 6: the farmer is overlapping the headland driving or headland turns or different obstacles are causing overlap.

Based on our results, the usage of GNSS assistance would easily cut the amount of overlapping in half. The section control was calculated to decrease the overlap by 30%.

CONCLUSIONS

In this study, we managed to calculate the overlapping percentage for spraying, sowing, harvesting, rolling, cultivating and fertilizing works by using the low-cost GPS and the implement status information. We determined different elements for overworking and measured them for spraying works. Our main findings in this study were:

- based on 92 field drives, the spatial overlapping in regular spraying works was 15.7% with 16 meter implement,
- the difference between two experienced drivers were only 0.8%,
- the overlapping happens near headlands and on parallel tracks,
- measured overlapping in combine drilling work was 7.7% on average,
- accurate automatic steering system decreased the overlapping in combine drilling work from 8.3% to 4.3%,
- there is no direct connection between the amount of overlap and the size and shape of the field.

Regular grain farming field operations are not very accurate without any modern steering assistance and machine control. The 15% average overlapping on spraying works is huge. Also overlapping with other machinery is significant and causes a lot of unwanted variation to the fields greatly complicating the precision farming acts. Simultaneously the farmer's time and pesticides, fertilizers, fuel and other matters are wasted. This was a successful study and showed one way how to exploit data from our Cropinfra-platform.

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