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Potentials of an ICT-supported bailing process

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Abstract

The global demand of agricultural products is growing steadily. Therefore the efficiency of the overall processes shall be increased. Whereas the improvement of machine's technology is a common goal, additionally improvement of the operative process management offers opportunities in many cases.
In a post crop-harvest process many bales of straw are removed from the field or collected at the headland. Therefore several machines are used. In central Europe a tractor with front-loader is commonly used for loading the bales on another tractor with attached trailer. The efficiency of this process depends strongly on the experience and overview of the tractor-driver. The goal is to find a suitable sequence of the approached bales to minimize the driving distance on the field in order to save fuel, working time and to reduce the risk of soil compaction. Therefore several scenarios will be presented.

Keywords: baling, logistics, ICT

1 Introduction

Crop residues, as straw, have been used for animal feeding and bedding over centuries. Today the harvesting process is followed by baling into small or large square or round bales. They have to be picked up on field and stored temporarily or permanently at the headland or transported to the required location at the farm.

1.1 Post harvest process with round bales

Large square bales have advantages over round bales in terms of transportation and storage. Their disadvantages are the lack of manual manipulation possibilities on the farm, power requirements and costs. The Austrian board on agricultural engineering and rural development (ÖKL) has indicated average net investment and hourly costs; costs per ton can be derived from KTBL-values (Table 1).
However, if straw is harvested and collected from the field for own use it is typically round baled in Austria. The discharge is done by a tractor with front-end loader and a trailer which is often attached to a second tractor. The bales are loaded onto the trailer by the loader. The driving distance depends on the field-position of the trailer and the bales. To minimizing the driving distance the trailer should be surrounded by the number of bales that matches its capacity.

Table 1: Average costs of large square baler and round baler (ÖKL, 2014; KTBL, 2012)

Machine	New machine invest costs (€)	total hourly costs (€/h)	total costs per ton (€/t)
Large square baler (0.8/0.9 × 1.2 × 2.4 m)	155,000	213.28	17.77
Round baler (Ø180 cm variable)	41,000	112.01	12.45

1.2 Improved logistics with bale collecting trailers

Inventory farmers built collector trailers which are drawn by a tractor in order to pick-up the round bales and place them on a suitable place on the field. One design comprises a hydraulically adjustable drawbar in order to pick the bales from the right side of the tractor with a lifting fork (Holtmann, 1992). The platform is declined to the rear end. So the bales should roll backwards due to their gravitational force. For field-discharge the rear mounted landing flap is released. With this machinery the driver has to follow the paths of the baler. The design was utilized on a commercially available machine (Fasterholt, 2014).
Another concept makes use of a sideways pivoting fork to pick-up the bales from their plane end face (Pieper, 1997). The platform is equipped with a chain-drive to push the bales backwards. With this machinery the driver has to drive in cross-direction to the harvester´s paths.
Especially from Ireland other machinery is known but it still has not succeeded in central Europe so far. The self loading bale transporter comprises two cages which can be lowered sideways. The cages are open at the bottom end. The bales can be overrun and picked by lifting the cage. The machine is intended to accomplish the road transportation with the cages lifted and locked for safety reasons (Figure 1a).

(a) (b)

Figure 1: a) Bale carrier (Keltec, 2013); b) unloading in pairs (Krone, 2014)

With a combined baler/wrapper machine the bales can be discharged in pairs (even without wrapping). The wrapper then just acts as a collecting platform. The bale is unloaded from the platform by an operator command or automatically when the next bale is ready for discharge (Figure 1b).

1.3 Objectives

The objectives of this paper are:

(1) to apply a simulation tool with fixed parameters to find the best suitable position for a trailer which is loaded by a tractor with front-end loader
(2) to study the effect of randomized distance between bales
(3) to set up a procedure to minimize the overrun field surface

2 Materials and methods

2.1 Definition of model parameters

The rectangular model field is defined to be 495 m in length and 300 m in width, resulting in an area of 14.85 ha. The combine harvester´s working width is 9 m. The straw harvest yield is assumed to be 3,000 kg/ha and the bales pressed with high density resulting in a weight of 390 kg. The distance between two bales is then about 145 m. The calculated area per bale is 1,305 m², resulting in 114 bales located on this model field. The round bale trailer´s capacity shall be 9 bales. This means, that 13 duty cycles have to be driven (with an average of 8.77 bales).

2.2 Separation into plots

The goal is to separate the field into 13 plots (each representing a single transportation stint). Within each plot at maximum 9 round bales are distributed. The trailer shall be parked in the center of each plot for loading. The ideal plot shape would be circular. However, squares have been chosen in order to fill the defined rectangular field with a number of 13 plots. Correspondingly, each plot covers an area of 11,423 m² resulting in a theoretical side length of 107 m. A total number of 8 full squares could be placed, but with small rectangular stripes remaining in length and width being uncovered (Figure 2a).
Therefore the square-plots are stretched into rectangular-plots, to fully cover the field at least in one dimension. The stretched dimension is chosen in order to cover the defined number of bales and to obtain a plot length/width-ration close to one (Figure 2b).

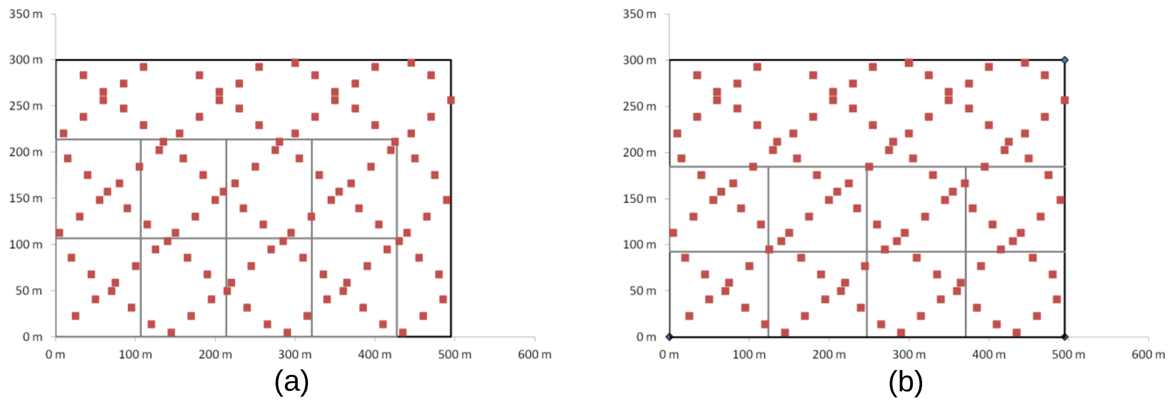


Figure 2: Segmentation of the whole field into plots; segmentation into squares (a) and stretched (b).

The remaining area which is not covered by the plots will be separated. This area's separation into plots is done in an iterative, second step (Figure 3).

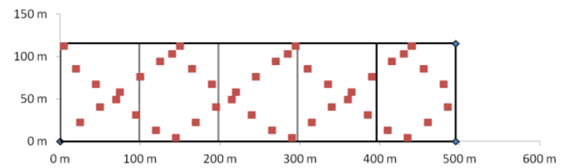


Figure 3: Segmentation of the remaining field area.

2.3 Field position of bales

Each red coloured mark represents a round bale (Figure 2 - Figure 6). It is assumed that the field entrance is nearby the left bottom corner and the driver of the baling machine starts at the first windrow. After arriving at the right field border he will continue driving to the left side in the second windrow. Assuming a homogeneous yield (resulting in the defined distance between bales) a rhomboidal pattern is generated, typically.

Next the distance between bales is randomized (145 m ± 10 m) with uniform distribution. The elementary rhomboidal pattern still remains (Figure 4).

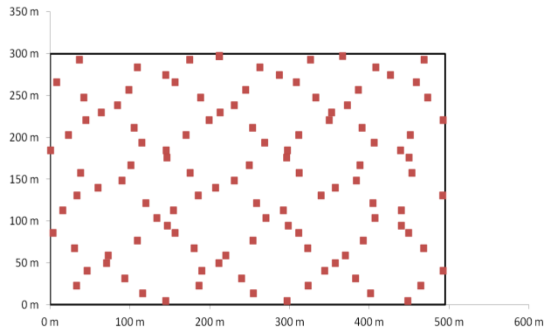


Figure 4: Randomized bale distribution on the field.

2.4 In-line drop-off

In case of release by the operator, two or more bales shall be placed on field side by side. In an advanced mode the stored bale can be released automatically by means of GPS inputs. The positions of previously unloaded bales were recorded and the new ones placed in line, accordingly (Figure 5).

The red marks represent a round bale with randomized position as described above. Blue dots are discharge positions. These positions require a collector platform attached to the baling-machine. The bale transporter can then be driven in cross-direction to the combine-harvester's. The advantage of such a procedure is that the overrun field-surface is reduced as the same paths can be used for bale collecting.

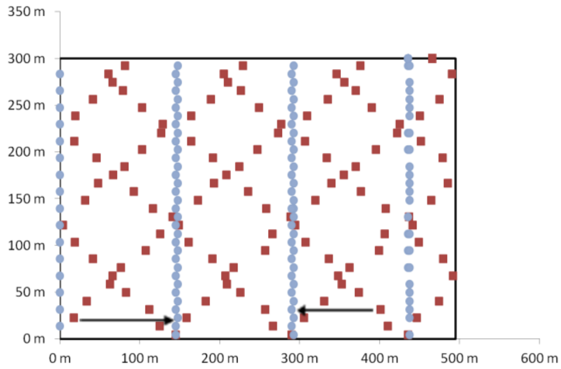


Figure 5: Randomized bale distribution converted to in-line distribution by using a collector during baling.

2.5 Simulation of field driving-distances

The driving distances on field were simulated for following scenarios:

I. Fixed distance between bales (145 m): A trailer is placed within a plot and loaded with a loader capable to carry one round bale. The trailer-position varies in a 5 m grid. The distances for the loader-tractor and the trailer (from field entrance) are calculated for each position of the trailer within the plot and cumulated over the whole field.

II. Randomized distance between bales (145 m ± 10 m): The same procedure as described above is applied.

III. Randomized distance between bales and in-line drop-off: The trailer is located next to the bale-row, adjacent to midpoint of the bales to be loaded. The trailer is assumed to be stopped until it is fully loaded or needs to drive to the next row.

IV. Randomized distance between bales and in-line discharge: The bales are collected by a self loading bale transporter instead of a trailer loaded by a tractor-loader.

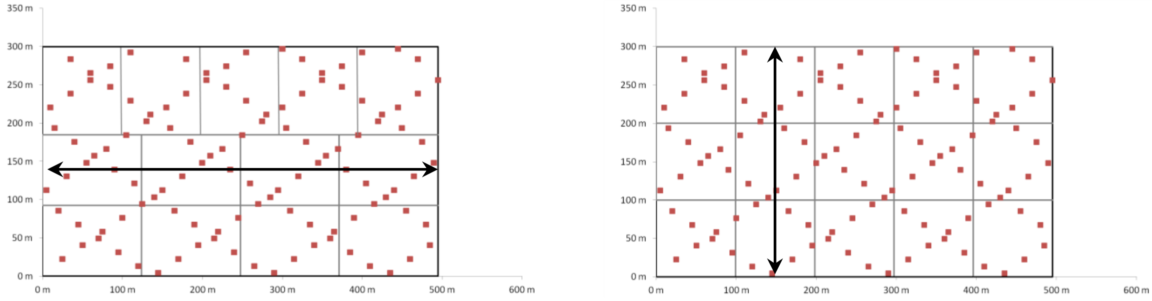
3 Results and Discussion

A rectangular model field was separated into plots. Each plot comprises bales for one duty cycle of the trailer.

3.1 Influence of trailer capacity on plot distribution

The loading capacity of any trailer determines the number of duty cycles and subsequently the number of plots. Basically we try to find square plots on the field and stretch them in the length- or width-direction. With a chosen capacity of nine bales per trailer a total number of

13 duty cycles is needed (see 2.2). The appropriate plot distribution is illustrated in Figure 6a. The plots are stretched in length. The resulting plot size is then 123.8 m × 92.3 m. The rest area of 300 m × 115.4 m will be split into 5 plots subsequently.



(a) (b)

Figure 6: Plot distribution on the model field with a trailer capacity of (a) nine bales and (b) eight bales.

Once we alter the trailer capacity, the number of plots is adopted accordingly. Therefore the plot-dimension to be stretched might switch. A trailer capacity of eight bales defines a new plot distribution as shown in Figure 6b.

3.2 Trailer position within the plot

Within every plot the distance from the bales to the trailer has been calculated for different parking positions of the trailer. A 5 m × 5 m grid overlay representing possible parking positions for the trailer was used to sum up calculated distances to each bale. The colour green in Figure 7 indicates relative short distances, red colour long distances for all bales of the trailer. Obviously, parking in the plot`s centre is a good strategy for a pattern with fixed distance between bales. For every plot the ideal parking distance within a 5 m × 5 m screen has been derived.

Scenario I

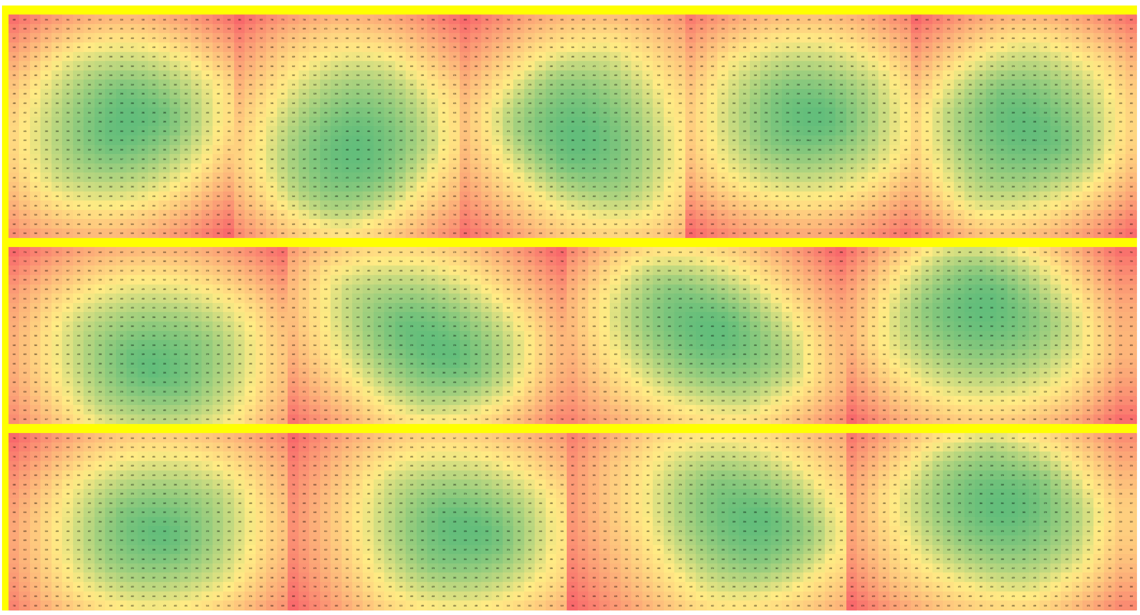


Figure 7: Optimum parking position of the trailer for loading with fixed distance between bales.

As indicated in Figure 7 the result on the parking position is rather stable. The driving distances for parking at plot centre or at optimal position are given in Table 2.

Table 2: Driving distances for the loading operation of the trailer

Plot no.	Distance optimal parking position – plot centre (m)	Driving distance parking in plot centre (m)	Driving distance parking in optimized position (m)
1	8.95	320.0	310.1
2	18.79	352.8	324.9
3	24.40	336.9	305.0
4	20.08	369.3	394.9
5	18.96	350.8	321.5
6	12.09	373.0	370.6
7	3.83	467.4	465.2
8	16.43	401.5	384.5
9	6.13	282.1	280.9
10	13.47	468.8	459.1
11	7.32	397.7	396.4
12	13.02	254.9	247.3
13	2.35	305.1	305.2
total	**165.82**	**4,680.3**	**4,565.6**
average	**12.76**	**360.0**	**351.2**

The cumulated difference of driving distances on the field is just 114.7 m.
With the way - driven by the trailer - from the field entrance to the individual plots and back again and the loader distances summed up, the total driving distance on the field are 10,794 m for plot centre and 10,845 m for optimal parking position. The minimized distances of the loader are cannibalized as the trailer ways are suboptimal for that strategy and lead to slightly increased overall driving distances.

Scenario II

The same procedure is applied to the randomized bale distribution pattern (145 m ± 10 m).

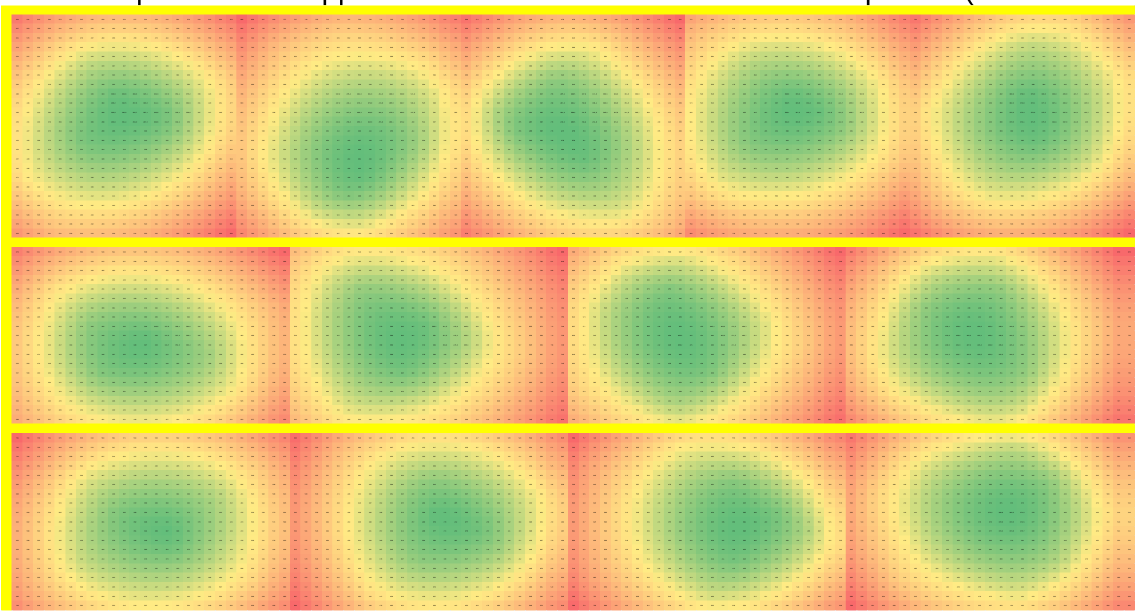


Figure 8: Optimum parking position of the trailer for loading with randomized distance between bales.

Figure 8 shows that the optimal parking position is still nearby the plot centre. The additional distances between plot centre and optimal parking position are given in Table 3.

Table 3: Driving distances to load the trailer with randomized bale distribution (loading operation only)

Plot no.	Distance optimal parking position – plot centre (m)	Driving distance parking in plot centre (m)	Driving distance parking in optimized position (m)
1	8.95	343.1	337.0
2	8.49	279.4	270.0
3	18.64	408.1	391.3
4	12.96	376.5	370.5
5	4.16	330.0	327.0
6	11.67	373.3	361.9
7	11.47	433.3	422.5
8	2.47	426.1	425.1
9	8.95	293.2	290.9
10	8.49	451.4	431.4
11	18.64	278.5	276.5
12	12.96	394.4	387.3
13	4.16	374.7	370.9
total	**126.90**	**4,762.0**	**4,662.3**
average	**9.76**	**366.3**	**358.6**

The cumulated difference of driving distances on the field is just 99.7 m.
With the way - driven by the trailer - from the field entrance to the individual plots and back again and the loader distances summed up, the total driving distance on the field are 10,876 m for plot centre and 10,833 m for optimal parking position. Here minimized loading distances are also beneficial overall.
In both cases the additional driving distances on the field are nearly negligibly in case of the trailer not parking exactly at the optimal position. Therefore it is recommended to park the trailer at the centre of each plot to reduce driving distances. An app on a mobile phone with GPS system could be helpful to direct the driver to the center.

3.3 Driving distance with bales in-line

Scenario III

Once the baler is equipped with an attached platform with a capacity of at least one bale, the bales can be unloaded in pairs. This would change just the pattern of the distributed bales. The average driving distances still would nearly be the same, as long as the tractor-loader can lift just a single bale.

Scenario IV

In alternative the platform might be used to discharge the bales in rows across the harvester's driving direction. In the first windrow the baler discharges as soon as the bale is ready. The positions might be recorded automatically. The bales drop-off in the second and the following windrows has to be delayed unless there is a bale located in the previous windrow (Figure 9).
This arrangement would fit to the bale carrier as shown in Figure 1a. The driving distance on field would be then 12.575 m including the distances from the field entrance.

This makes an additional driving distance of about +16 % compared to scenarios I & II. But the compaction of soil would decrease in average, as the overrun surface is reduced. In advanced mode the row-positions from previous years can be recorded and utilized again.
If a tractor with loader is used in scenario IV then the total driving distance on field would be 16.458 m which equals about +52 % more than in scenarios I & II.

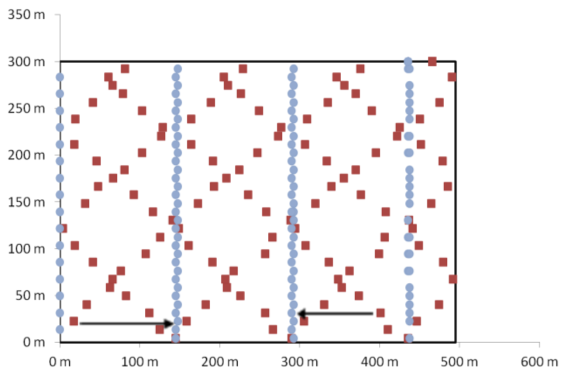


Figure 9: Discharge of the bales in line.

4 Conclusions

For a model based calculation a rectangular field and a trailer transport capacity was defined. According to the requested number of duty cycles the field was segmented into plots. The plots were stretched in one dimension and the remaining field area segmented again.
Once the plots are defined the optimal parking position of the trailer is nearby the plot centre to minimize the driving distance with the tractor-loader. The results are stable for two calculated bale distribution patterns. The total driving distances on the model field are about 10.8 km. It seems that the focus has to occupy an optimal plot distribution and not an optimal trailer position in the plot.
A bale distribution in-line - which could be realized with a baler/wrapper combination - serves the reduction of soil compaction. The driving distances do increase especially with tractor loading (about +52 %) or with self loading bale transporter (about +16 %).
The placement of the bales on the field has to depend on the targeted goal (minimize total driving distance, or minimize overrun field surface). Once the bale positions on the field are known (from the baler) or predicted (by yield measuring on the combine), the field shall be segmented into plots where every plot contains the appropriate number of bales for loading. The driver of the trailer can make use of an application on a tablet/mobile phone to navigate to the plot center.

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