Analysis of influencing factors and decision criteria on Infield-Logistics of different farm types in Germany

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Abstract: In future increasing production efficiency in agriculture will not only be achieved by rising machinery working widths but more and more by optimization of entire production process chains. The more machines are interacting the higher will be the specific optimization potential. Navigation not only to the fields but also within the fields will certainly contribute to make use of these efficiency reserves. Necessary therefore is the knowledge of potential influences on infield-logistics to be able to navigate agricultural machinery in the fields effectively and process optimized. Preliminary studies based on GPS-lane analysis in different German agricultural regions and in Central Canada show that decisions on specific infield patterns to a certain degree depend on unchangeable factors such as field geometry or field access points. Nevertheless, regarding infield-logistics farm managers and staff members mostly act farm specifically as well as depending on technology or situation and furthermore often intuitive. The examination is based on expert interviews with farmers of all agricultural regions in Germany. Rural mixed farms with simple machinery are considered as well as large agricultural cooperatives which farm thousands of hectares using track guidance and other electronic assistance systems. By aerial images of their arable land the individual decision behavior should be analyzed to specify the "soft" influencing factors. First result shows that farm managers using guidance tracking or electronic assistance systems, such as Section Control, increasingly attune their infield-logistics to direction giving obstacles like power lines. Livestock farmers rather focus on the application of organic manure, where road networks, road conditions respectively and possible field access points become important due to the required supply logistics. Sugar beets make great demands on infield patterns because of relatively low bunker sizes compared to the mass to be transported as well as the positioning of the beet clamp. Afterwards the obtained influences can be integrated into a navigation tool for optimizing infield logistics. Thus process efficiency can be further increased.

Keywords: agricultural logistics, process optimization, infield navigation, vehicle guidance, decision criteria

Citation: Mederle, M., H. Bernhardt. 2017. Analysis of influencing factors and decision criteria on Infield-Logistics of different farm types in Germany. Agricultural Engineering International: CIGR Journal, 19(2): 139–148.

1 Introduction

Logistics requirements in modern agriculture have been increasing enormously for some time. On the one hand, this development is due to growing farms, of which farm-field-distances are rising continuously. On the other hand, new branches such as the production of biogas require steadily growing transports of any kind (Götz et al., 2015).

Received date: 2016-10-12 **Accepted date:** 2017-05-04

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An optimal utilization of all used machines is of high importance, particularly because of unpredictable weather influences (Streicher et al., 2014). The more machines are interacting in complex process chains, the higher is the optimization potential of the logistics behind it (Bochtis et al., 2007a). This is applicable for material input operations, such as seeding or fertilizing, as well as for material output operations, like harvesting. In both cases, service units are required (Zhou et al., 2015). Badly organized process chains lead to higher shares of dead times during the process and result in rising costs per unit produced (Li et al., 2013).

Some software solutions already help at planning and organizing of complicated agricultural processes

(Bakhtiari et al., 2013). Especially for harvesting, optimization tools can indubitably help rising process efficiency because 30 % of machinery costs are allotted to the harvesting process (Bochtis and Sørensen, 2010). Entire process chains can be simulated, analyzed concerning efficiency and finally optimized theoretically (Ali et al., 2009). These analysis and optimizations often are conducted post-harvest and base on experience (Costa et al., 2014). Hence they mostly are not really feasible for predicting. Agricultural production processes do not take place under laboratory conditions but they are influenced by several hardly unpredictable factors such as time slots, as well as soil or weather conditions (Bernhardt et al., 2013). Many scientific approaches of optimizing infield logistics do not really respect these real-life conditions (Kusumastuti et al., 2016). To integrate them would make optimization tools more practicable for farmers.

Another parameter for making agricultural production processes more efficient is path planning in the fields (Zhou and Bochtis, 2015). Not only higher engine power or higher machinery working widths will contribute to enhancing efficiency in future agriculture but also optimized techniques of agricultural processes that are well organized and coordinated (Mederle et al., 2015a). Infield logistics especially gets into focus when several operating machines are working together in one field. In this case, an optimized coordination of all process participating equipment is of very high importance (Bochtis et al., 2007b). Process efficiency of operations as tillage, mostly working with only one single machine, is mainly depending on the type of turning maneuvers. Zhou et al. (2015) tested different kinds of infield patterns with different turnings and concluded that influences like machine parameters, operator's experiences or the field geometry affect the choice of the most efficient turning type.

By now researches concerning logistics rather deal with navigation on public and field roads till the edge of the field which is useful for contractors or big farms with changing staff to help finding the fields to be worked. This kind of navigation is pure line logistics where the field represents the defined target point (Götz et al., 2014).

By contrast to road logistics infield logistics is known as area logistics. Farmers can choose an endless number of possible lanes to work their fields but only a certain part of them is realistic and practicable. Particularly since the use of automatic guidance different ways of headland turnings contribute to significantly reduce the overrun soil surface at the headland area by up to 50% (Bochtis and Sørensen, 2010).

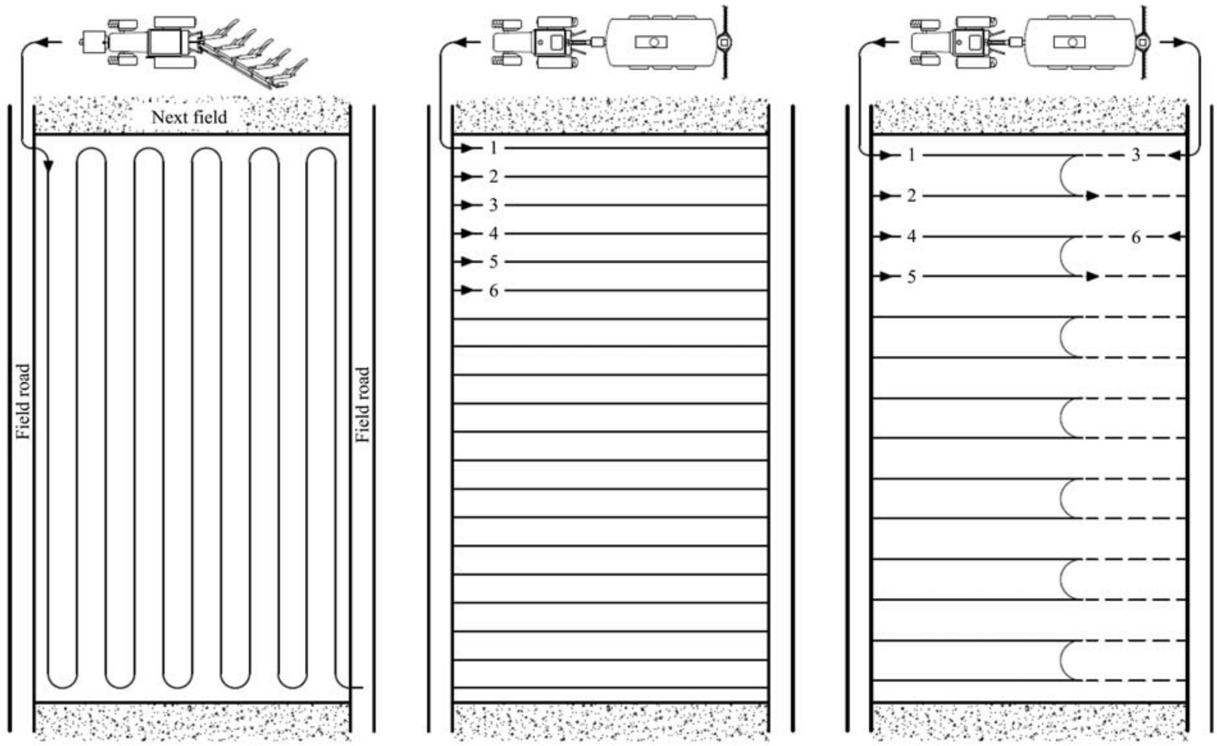
There are many reasons why farmers work their fields the way they do. Although there has been done a lot of optimization concerning infield-logistics during the last years, e.g. Søgaard and Sørensen (2004) and Berruto and Busato (2008), farmers sometimes still do not implement these theoretical optimizations. The most important goals to optimize are reducing fuel consumption, reducing dead distances as well as maximizing process times in the fields. These calculations mostly base on field geometry and do not really take into account the reasons for certain farm-specific infield-strategies. There are certain reasons why farmers do not work their fields as the optimization pretends (Mederle et al., 2016). These influences partly differ from farm to farm and are often based on experience or intuition. The aim of this research is to find these "soft" influences as well as the different decision criteria of farmers and to consider them when optimizing infield-logistics.

2 Example scenario

To illustrate the intention of this study, Figure 1 shows a rectangular field with three different infield scenarios.

The field is surrounded by neighbor fields north and south as well as by field roads east and west. There are different approaches to tackle the problem and not every kind of farmer would work this field exactly the same way.

Scenario A shows an example for cultivation. Neither supply- nor removal-logistics is needed. The field roads will not have any influences and due to the geometry of the field the farmer usually will choose the longer north-south lane to reduce turning times while maximizing process times. Arable farmers who are not reliant on the application of organic manure but do all their fertilization with mineral fertilizer also would choose the north-south lane because they do not have to move that much amount of tons. Scenario B and C represent operations where supply-logistics is required, e.g. slurry application. Depending on tank volume and amount of application farmers with livestock farming will accept the shorter lane from west to east to use the direct entrance and exit to the field. Thus it is possible to avoid unnecessary driving with the spreading unit in the field which reduces the danger of soil compaction. Field roads now surely have influence on the infield-strategy and probably the farmer will do all the operations in east-west-direction (Mederle et al., 2015b).



a. Most efficient way of working for material neutral operations (e.g. tillage)

b. Material input/output operations without pretended tramlines

c. Tramline distances pretend working width

Figure 1 Different infield-strategies depending on various operations

The difference between scenario B and C is the working width of the slurry tank. In B it is operated with a smaller width to be able to cover the whole distance from the western to the eastern field edge. Scenario C is to illustrate slurry application in growing plant stocks with defined tramlines. Depending on farm size or machinery equipment the distance between the tramlines is between 15 and 36 meters. Tramline systems play a significant role in German arable farming because crop cultivation mostly is practiced with high intensity. In these tramlines farmers go up to five to eight times with the sprayer or fertilizer spreader for plant maintenance. Livestock farmers additionally fertilize their crops with manure. Particularly in case of bigger distances one manure tank is not enough for covering the whole field length. Reduction of the working width is no option because too many plants would be irreversibly damaged. To face this problem there are two possibilities: either reducing the application rate or to take three tanks for two tramlines (Scenario C).

The system due to which farmers work their fields is depending on several influencing factors that are hardly researched scientifically. The goal of this research is to identify reasons for certain infield strategies as well as to analyze and judge them.

3 Material and methods

Main part of the research is a survey of numerous farmers all over Germany which is conducted in the shape of an expert interview. The advantage of direct conversation with the farmers compared to a standardized questionnaire is that farm-specific information can clearly be registered. Farmers who are willing to participate in the study give comprising insight in their way of working.

Thus good data quality is achievable.

The variety of German agriculture is very broad as there are different structures in the north and east of the country compared to the south. Arable farming in the north and east is rather large-scaled. Farms are often organized as agricultural companies whereas family farms with mainly smaller sizes dominate the structure in the south. To cover as many different types of farms as possible is intended. Various types of farms are expected to have different preconditions concerning field shapes and sizes or machinery equipment and technologies used for cultivating their fields. All these factors are said to have influence on different infield scenarios.

Preliminary studies based on GNSS lanes have predicted that influencing factors on infield strategies strongly depend on farm specific parameters. For this reason, the structure of the survey is rather qualitative than quantitative in order not to lose valuable information. However, regarding the evaluation of the study, it is important to be able to compare all the statements of the different farmers. Therefore, every conversation is carried out based on a certain conversation guideline.

3.1 Guideline of the questionnaire

Every interview starts with general questions on the particular farm such as farm size, technical equipment or available manpower. Based on this information it is possible to range and classify the survey participating farms.

Next part covers general questions on infield strategies. This section is intended to focus on reasons for certain infield patterns as well as to answer questions concerning specific field arrangements or area divisions. Examples might be as follows:

- Do you work your fields always the same way or is this depending on the currently cultivated crop?
- What parameters do you focus on when you consider your infield strategies?
- Do you zone your fields in certain subdivisions or are you always trying to work biggest fields possible?

Third section of the guideline deals with issues concerning headland, patches and tramlines. The central question in this part is the particular way of headland designing as well as the question of working in special patches or not.

Further parts of the interview concern about operation steps as tillage, seeding, plant protection (fertilizing or spraying) as well as grain harvest. Livestock or biogas farmers are additionally asked about slurry or organic manure application affairs.

The last chapter is mainly foreseen for larger scaled grain farms where certain operation steps such as tillage or particularly grain harvest are done by more than one machine at the same time. Especially, when working in such complexes the reasons for special infield strategies are extremely interesting and reasonable to analyze.

3.2 Already interviewed farmers

Table 1 shows 12 farmers of different parts in Germany with various agricultural preconditions that have already been interviewed in the first step of the study.

Table 1 Already interviewed farmers

Farm size	Total number	Livestock farming	Sugar beet cultivation	Use of GPS technology
<100 ha	3	3	1	0
100-500 ha	6	0	5	4
>500 ha	3	1	2	3
Total	12	4	8	7

The participating farms have been clustered in three different categories depending on their amount of arable land in hectare. Less than 100 ha is a typical size for family farms in the south of Germany. The second category (100-500 ha) is appropriate to compare farms of North and East Germany with those in the southern part because these kind of farm sizes can be found in every German agricultural area. The third class includes farms with more than 500 ha arable land. This size is typical, especially for farms in the northern and eastern part of Germany.

The fact whether they do livestock farming is important to know because otherwise they cannot answer certain questions on organic manure application. Furthermore, slurry application partly seems to have big influence on infield logistics. Sugar beet cultivation is also an important criterion. Due to the special row crop system and the relatively big amount of yields to be transported, sugar beet farmers change their infield strategies more often for sugar beets than because of grain crops. The use of electronic assistance and track guidance systems also represents a factor that has to be considered when talking about infield logistics. Benefits from working in patches, implementing of Controlled-Traffic-Farming or systems as Section Control are only possible by using GPS technology.

Three of the participants farm less than 100 ha but all these three also do livestock farming for having more refinements per hectare. One of them cultivates sugar beets whereas no one uses GPS technology. Half of the already interviewed farmers belong to the second group of 100-500 ha arable land. Five of them grow sugar beets and two thirds use GPS assistance systems with RTK accuracy. Three participants farm more than 500 ha. This range is from 640 to 1200 ha. All these three use RTK technology but only two cultivate sugar beets.

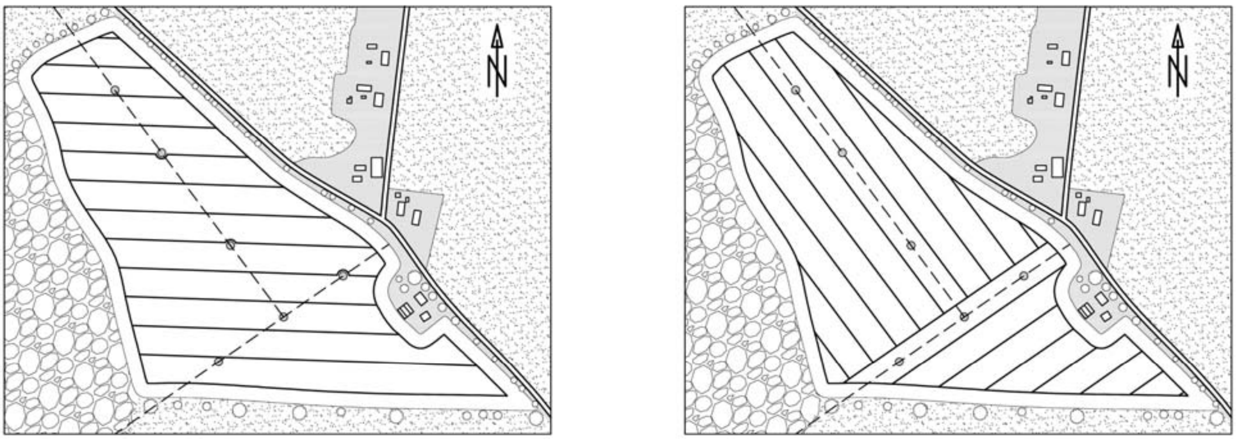
4 Result and discussion

First result of the evaluation show that influences on infield logistics can be categorized in two different groups. There are so-called "hard" factors which are not or only hardly changeable, such as field shapes, field sizes or field access points. Of course the geometry of a field strongly affects the working direction of this specific field. But as mentioned in the example scenario further issues have to be taken into consideration when talking about infield logistics and implementing a certain tramline system.

These "soft" factors can be changed quite easily because they strongly depend on organization and structure of a particular farm. Examples therefore are e.g. facilities with manpower as well as the utilized mechanical equipment or the employed technology of electronic assistance systems.

4.1 Influence of power lines when using electronic assistance systems

Especially the use of electronic assistance systems, such as parallel guidance systems or Section Control, changes the habits of the farmers concerning the system of working their fields. Seven out of 12 already interviewed farmers use GPS technology and four of them indicated that power lines influence their infield strategies. Figure 2 shows this fact based on an example of electric power lines crossing the field.



a. Way of working without using electronic assistance systems b. Adaptation of infield strategy to the power lines due to electronic assistance systems

Figure 2 Way of working the field without (a) and with (b) using electronic assistance systems

In former times, when no electronic assistance was provided, the entire field has been worked just along the straightest edge (Scenario A). All tramlines in the field were parallel to each other except the headland tramline which surrounds the whole field. Wedges and angles were unavoidable and all caused by the natural shape of the field. One of the biggest disadvantage of this particular way to work appears at spraying, because the boom has to be flipped at every power pole which takes about one to two minutes every time. Farmers who cultivate their crops very intensively and who do even their fertilization with the sprayer by liquid fertilizer have to work this single field about six to eight times with the sprayer. In consequence assuming these six power poles in the field they have to flip the sprayer boom about 40 times which takes about 60-90 minutes of valuable working time during good weather conditions.

Scenario B shows exactly the same field after the implementation of electronical assistance. Farmers are now able to attune their infield strategies to the power lines, so they do not have to spend that much time for flipping the sprayer boom anymore. Time savings also are an issue when talking about B-Patterns at the headland region. Depending on the used machinery and the current soil preconditions reductions by up to 17% are possible (Bochtis and Sørensen, 2010). In Scenario B, seeding is started along the two power lines so that the tramlines are exactly half the sprayer width next to the poles. Thus the outer section of the boom only touches the poles which does not require to flip the whole boom. The fact that this scenario results in even more and sharper angles at the headland is negligible because of Section Control. This electronic assistance system prevents double applications automatically which results in resource savings of up to 25% (Stombaugh et al., 2009). Farmers are now able to attune their infield strategies rather on other issues than on angles caused by the field geometry. A further reason for implementing this kind of tramline system might be the fact that plant protection or liquid fertilizing actions are mainly carried out by senior farm executives who rather focus on these operation steps when considering infield logistics.

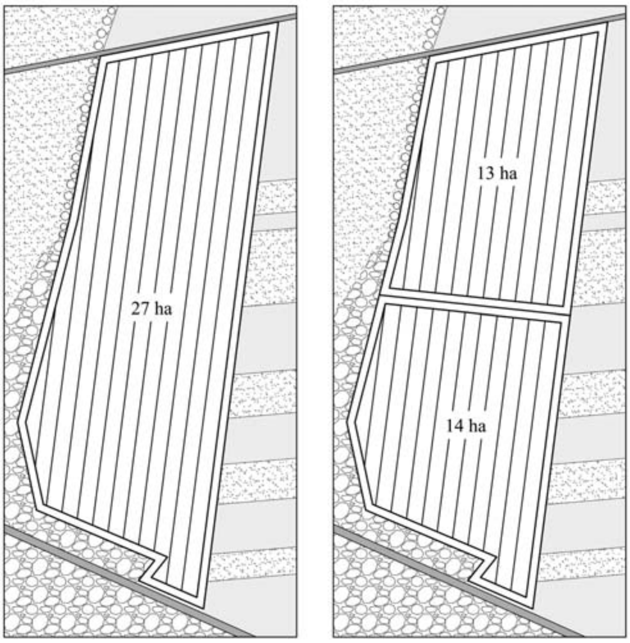
4.2 Influence of sugar beet cultivation

By now the survey shows that sugar beet is a crop with very high influence concerning infield logistics. Two of the main issues are high mass yields per hectare as well as market regulation measures as supply quota. Additionally, the positioning of the beet clamp requires some considerations because removal logistics is mainly carried out by trucks which are not able to use field roads of bad quality. Further soft influencing issues are e.g. weather conditions which particularly affect the organization of the harvest process chain. Sugar beet harvest usually happens in autumn from September until December with high probability of wet conditions that will inevitably result in soil compaction. Thus some farmers prefer as little machines as possible in the field. This kind of harvesting system is called single-phase harvest. The sugar beet harvester does the work completely on its own without any additional unloading trailers.

4.2.1 Influence of sugar beet cultivation on field arrangement

Figure 3 shows a typical case for farmers dividing their fields for growing sugar beets. One reason for this measure is the farm-specific supply quota. No farm is allowed to deliver more than this contractually committed quantity of sugar beets. In the example of Figure 3 this amount is equal to the estimated yield of 13-14 ha cultivated sugar beets. If the farmer wants to grow sugar beets on this particular field of 27 ha in total, he has to separate it into several subunits for not exceeding the delivery volume.

There would be two possibilities of separating, across or along the longer edge. Thus further influencing issues have to be considered. Several reasons suggest to cut the field the way shown in Figure 3.



a. Field arrangement for grain crops b. Field subdivision due to sugar beet cultivation

Figure 3 Field arrangement depending on sugar beet cultivation

As mentioned before the harvest system plays a significant role. This farmer explicitly wants to work without multiphase logistic systems in the field because of soil protection. Severing the field length ensures that the harvester does not have to cover more dead distances than unconditionally necessary with full beet tank. Therefore, the farmer is willing to accept more time for turning and unloading while standing. Indeed, this prolongs the whole harvesting process and makes it less efficient but on the other hand less machinery and less manpower is required. Other farmers rather focus on process times of the expensive harvest machine accepting more vehicles in the field.

Another issue is the beet clamp that should be positioned parallel along public roads or at least well developed field roads because removal logistics is completely carried out by trucks and lorries which cannot run on field roads of bad conditions. The main working direction of the field should be vertical to the beet clamp. Thus ineffective dead distances with full tanks and without harvesting can be kept low.

Bochtis et al. (2010) confirm these reasons for cutting the field along the shorter edge. They revealed cost savings of up to 9% considering the entire production process from tillage until harvest when working a field not along the longer but the shorter edge. This efficiency increase is mainly due to the material input operations as fertilizing or spraying, where additional service units are necessary and the road network gets into focus.

4.2.2 Influence of sugar beet cultivation on headland designing

In some cases, sugar beet cultivation strongly affects the way farmers arrange the tramline system of their fields. The positioning of the beet clamp, a major influence, pretends the main working direction. Further decision criteria such as the preference of a certain type of harvest organization, e.g. single-phase harvest, have to be adjusted. According to Jensen et al. (2012) the usage of supporting unloading vehicles can significantly affect the productivity of the whole system, but the decision-maker has to make compromises. On the one hand field lengths are wanted to be as long as possible to have both high process efficiency and less time needed for turnings. On the other hand, dead distances with full bunker of the harvester or with heavy unloading machinery lead to soil compaction that causes decreasing yields.

A feasible solution for a single-phase harvesting system with too long field edges would be a special headland designing as shown in Figure 4.

The sugar beet harvester is not able to cover the whole distance from one edge of the field to the other, which in this special case is 700 m. Together with the way back to the western edge the harvester would have to make 1400 m with one bunker. This is too much and would lead inevitably to dead distances. Thus the farmer decided to enlarge the headland at the eastern side of the field to reduce the distance of the main field to 520 m. This adaption ensures that the harvester’s tank size suffices for one working round which is now 1040 m.

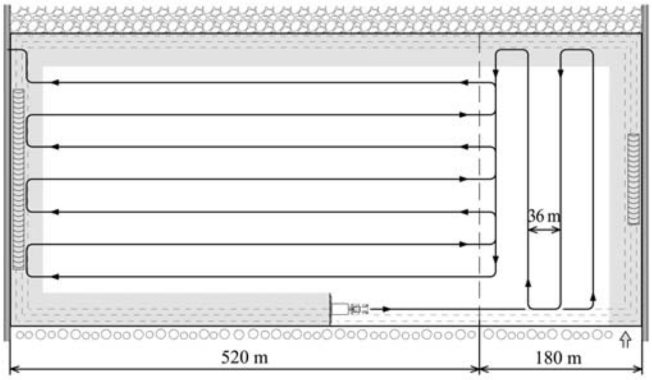


Figure 4 Influence of sugar beet cultivation on headland designing

When cultivating grain crops such as barley, wheat or canola, it would not be necessary to arrange the tramlines this special way. Firstly, there would be no problem to cover the whole distance with one grain tank. On the other hand, combine harvesters do not mandatorily have to take the same routes or working directions as the seeding machine pretends. Tramlines could be arranged as long as possible for high process efficiencies in plant protection measures with little turning times. This is definitely useful because in conventional agriculture, that is run very intensively, machines have to pass the culture up to eight times for fertilizing or spraying whereas harvest could be done across the tramlines as far as necessary.

In the particular issue of working directions and tramlines sugar beet cultivation is a very special challenge because of its row crop system. To get the harvest done with good results of working quality the beet harvester has to take exactly the same working direction as the seeding machine. Furthermore, it is not recommendable to make tramlines across the beet rows but along them because of damaging beets and consequently lower yields. Thus the seeder already has to work the field just the same way the beet harvester should harvest it afterwards. Additionally, plant protection measures like fertilizing or spraying also have to be carried out the same working direction that is already implemented by the seeding machine and the tramline system.

4.3 Influence of general agricultural structure

One of the major influences on infield logistics is the common agricultural structure the specific farm is located in. Figure 5 shows an example for that issue.

This particular field has a size of 23 ha. According to Engelhardt (2004) in Eastern Germany the average field size is 49 ha and thus a field of 23 ha is quite small anyway and probably no farmer would even think about separating the field in different subdivisions because the general opinion is ‘the bigger a field the more efficient work can be done’. Unnecessary subunits only would cause more time for turning or machine set-up.

Looking to the southern part of Germany, e.g. Bavaria, the situation is completely different. The field shown in Figure 5 is in possession of a typical family farm with arable land of 65 ha in total. Thus this single field is one third of the entire farm land. For spreading the risk as well as for adapting this field to the common agricultural landscape that is very small structured the farmer separates the field into different subunits of about 2-4 ha.

Another reason for the subdivision is the cultivation of sugar beets. Almost no farmer in Bavaria is in possession of supply quota that complies with 23 ha of acreage. Thus fields are subdivided and sugar beets only are cultivated on sites of good soil quality. Additionally, removal logistics by trucks has to be considered and ensured.

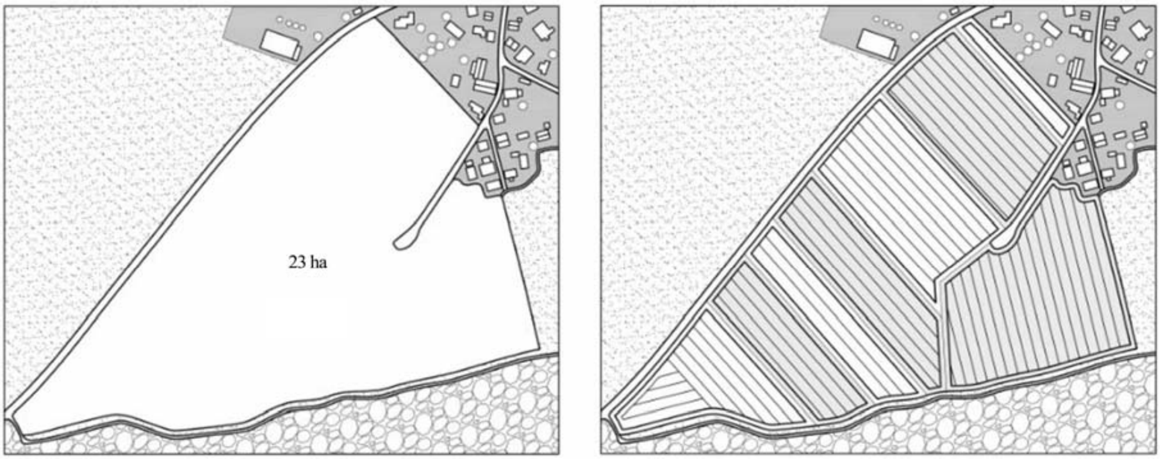


Figure 5 Influence of general agricultural structure on field subdivisions

5 Conclusions

Generally influencing factors on infield logistics can be categorized in “hard” and “soft” factors. Field shapes and the terrain of the landscape are one of the biggest influences that are hardly changeable. More difficult to detect are influences that are caused by farm specific organizational reasons, such as single-phase harvesting, or by technical issues, as e.g. saddled attachments. In case of harvest organization supporting units generally known contribute to significantly higher process efficiency (Jensen et al., 2012) but several farmers are still not willing to use them due to different reasons (e.g. lack of labor, soil compaction, underused special machinery).

It is clearly visible that the utilization of electronical assistance systems such as GPS guidance or Section Control influence not only the managing people on the farm that make the general decisions, such as attuning the infield strategy to power lines, but also the worker who carries out the work with the machines. Using guidance tracking allows making specific patterns that have advantages in the headland area concerning overrun soil surface or turning times. On the other hand, optimal headland turnings depend on many influences and wrong decisions of the operator lead to considerable decreasing process efficiency (Zhou et al., 2015).

Furthermore, because of the reasons mentioned above the cultivation of sugar beets plays a significant role when thinking about infield strategies. Especially the harvest as material output operation depend on various influences like machinery parameters as bunker volume, working width, plant population parameters as yield level or environmental parameters as weather or soil conditions.

Depending on the common agricultural structure and farm specific organization these influences might differ from farm to farm. In addition, they always have to be considered field individually.

In order to get a higher sample and results that are more detailed and more reliable further interviews will be carried out.

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