OPTIMIZING PATH PLANNING BY AVOIDING SHORT CORNER TRACKS

M. Spekken, J.P. Molin

Biosystems Engineering Department,"Luiz de Queiroz" College of Agriculture
University of São Paulo
Piracicaba, São Paulo, Brazil.

ABSTRACT

Reduction of non-working time for machines in field improves economical and environmental sustainability. Creating predefined tracks and routes in field maps by computer simulation, known as path planning, can reach solutions that increase the working efficiency of machines. Also it becomes more important with the growing adoption of controlled traffic farming practices and with the use of robots as farm machinery. A number of works have been developed for path planning to achieve this, but they were limited in optimization because of their aim to obtain full coverage in non-squared fields, always reaching small corners that are difficult and costly to be operated, with a representative area overlapped in the headlands of these corners. In this work an algorithm was developed that creates a series of tracks for a given field and a working direction and, afterwards, it detects corners where groups of tracks shorter than a given length are excluded from the field coverage, creating an uncropped area. By simulating different working directions in the field, an optimization to obtain the smaller loss for uncropped area, overlapped area and a reduced number of machine maneuvers is found. Two case studies were applied in the algorithm, an optimized path proposes a loss of 0.253% of area avoiding 5.69% turns on unprofitable tracks for a sugar-cane operation, and for a corn planting case study, overlap of coverage in headlands was 3.2 times higher in corner areas in relation to the whole field. The algorithm showed to be capable of optimizing paths on fields of different shapes and sizes.

Keywords: uncropped areas, field coverage, machine efficiency, modeling.

INTRODUCTION

Most of the modern agricultural land is cropped with the traffic of machines that spend a fraction of their time in unproductive operations (like maneuvering or loading/offloading agricultural goods) lowering their working efficiencies.

The efficiency is not a constant for a particular machine, but varies with the size and shape of the field, pattern of field operation, crop yield, crop moisture, and other conditions (Bochtis et al., 2008). Besides being time consuming, vertical disturbance of the soil is caused by the weight of the machine, and horizontal disturbances are caused by changes in the direction of travel. As a consequence the headland areas constitute "low productivity" field areas (Witney, 1996), and the disturbances can be aggravated with the trend of increasing size (and consequently weight) of machines (Kutzbach, 2000).

Rectangular fields have high field efficiency because the tracks are usually long and uniform reducing the number of maneuvers, but in irregularly shaped fields the efficiency is mined because of the parallel traffic behavior, mainly for straight working patterns. These issues linked to the recent development of guidance systems for machinery pushed the development of path planning.

Path planning, in an agricultural perspective, is a term used for defining in advance how a machine moves inside a field, mainly by computer simulation (Spekken and Bruin, 2010). Optimized route and path planning is one of the most important requirements voiced by farm managers and machine contractor managers as a way to develop an advanced integrated fleet management system (Sørensen and Bochtis, 2010).

Previous works have been carried out to obtain optimized machine traffic by reducing field complexity by splitting the field into simple shaped sub-fields, finding better working directions (Jin and Tang, 2006; Oksanen and Visala, 2007; Hofstee et al., 2009), and by finding more suitable turning patterns between adjacent machine tracks (Cariou et al., 2010; Jin and Tang, 2010) and non-adjacent tracks (Bochtis and Vougioukas, 2008; Spekken and Bruin, 2010).

Despite the results obtained in many path planning works, fields that are not limited by parallel borders will have tracks in corners of its shape. Figure 1 shows the results of optimized paths found by authors where the red squares enhance short corner tracks with low machine efficiency. Additionally to the number of turns, the narrow angle between the machine track and the field borders lead to types of turns that are more time consuming than borders perpendicular to the tracks (Spekken and Bruin, 2010). Also, the narrow turning angle leads to a higher overlap of field operations; it can be seen in Figure 2. In these corners the proportion of headland is more significant, leading to more overrunning of machine on crops and compaction of soil.
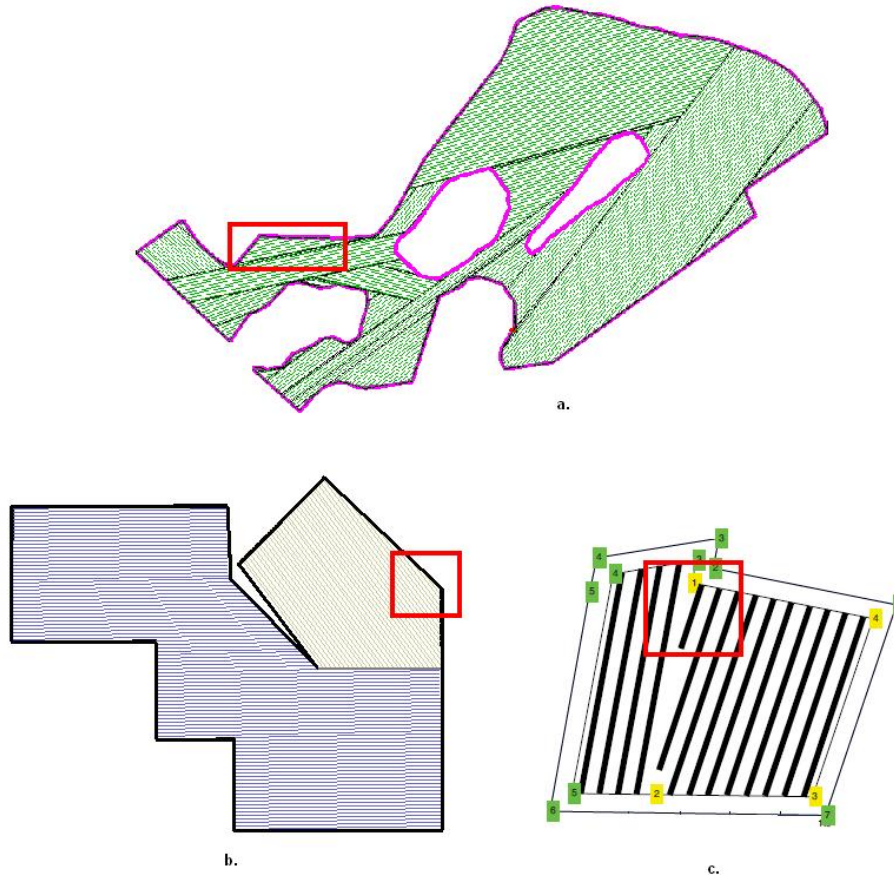
Fig. 1. Results of the field coverage algorithms which split the fields in order to reduce the number of turns The results were extracted from a. Oksamen et al. (2007), b. Jin et al. (2006) and c. Hofstee et al. (2009).
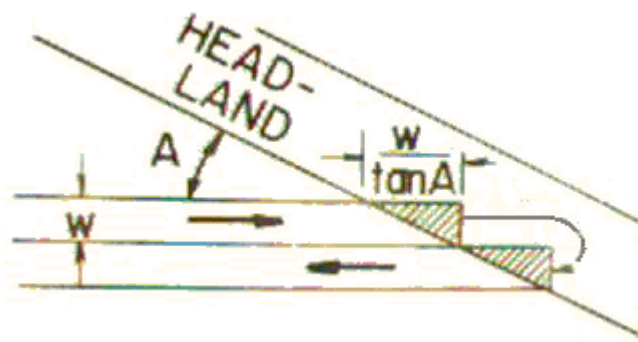

Fig. 2. Direction of work towards the border (angle 'A') influencing the size of a headland and the overlap area. 'w' is the width of the machine. Extracted from Witney (1996).

Considering these pointed impacts (economical and environmental) of growing crops in such areas, it could be more profitable to leave these areas uncropped.

Policies to keep uncropped areas with paid subsidies are applied in European countries, like the maintenance of grassy headlands and buffer zones in Belgium, Finland, Denmark and England (Longeville et al., 2007). Other countries like Brazil have a policy of demanding a specific fraction of the owner's property to be occupied by uncropped natural reserve (Brazilian Federal Law 4771/1965) under the penalty of fines. Also the use of tools for monitoring and allocating such areas have been studied with the use of Geographic Information Systems (GIS) and remote sensing (Longeville et al., 2007; Delalibera et al., 2007).

Uncropped zones applied as cost in path planning has also been studied, de Bruin et al. (2009) proposed a method to relocate areas of sub-efficient machine maneuvering to boundary strips so as to optimize the use of available space.

But the studies so far did not concern in eliminating the machine tracks located in field corners, but only to change their pattern. There is still lack of a method to discriminate machine tracks from areas of high environmental impact and low (or no) economic return. This study describes a method implemented in a computer algorithm to select and eliminate these tracks from a given threshold that can be economically calculated, and it simulates different machine working directions to obtain an optimized path considering the impact of turns, overlap of area and loss of cropped area.

MATERIAL END METHODS

An algorithm was developed as Visual Basic macros within Microsoft Excel. The input data is given by:
- field geometry, which is interpreted by the algorithm as one 2-D polygon (or more polygons in case of existing obstacles in the field), composed by vertices given in metric co-ordinates;
- machine width, given in meters;
- a threshold that defines the uncropped areas; it is the value that will identify corner areas using one of the two classifying methods: from a minimum length of tracks worth to be worked, or from a minimum area not worth to be worked.

The methodology is explained by the sequence of steps in Figure 3.

Create tracks for a given angle

With the machine width and the field geometry the algorithm creates a sequence of parallel straight lines in a given working angle representing the machine tracks (Fig. 3a). The sequence of tracks created start from the most western corner of the field and cover the whole field. The algorithm creates tracks in fields of different shapes and also with the presence of obstacles.
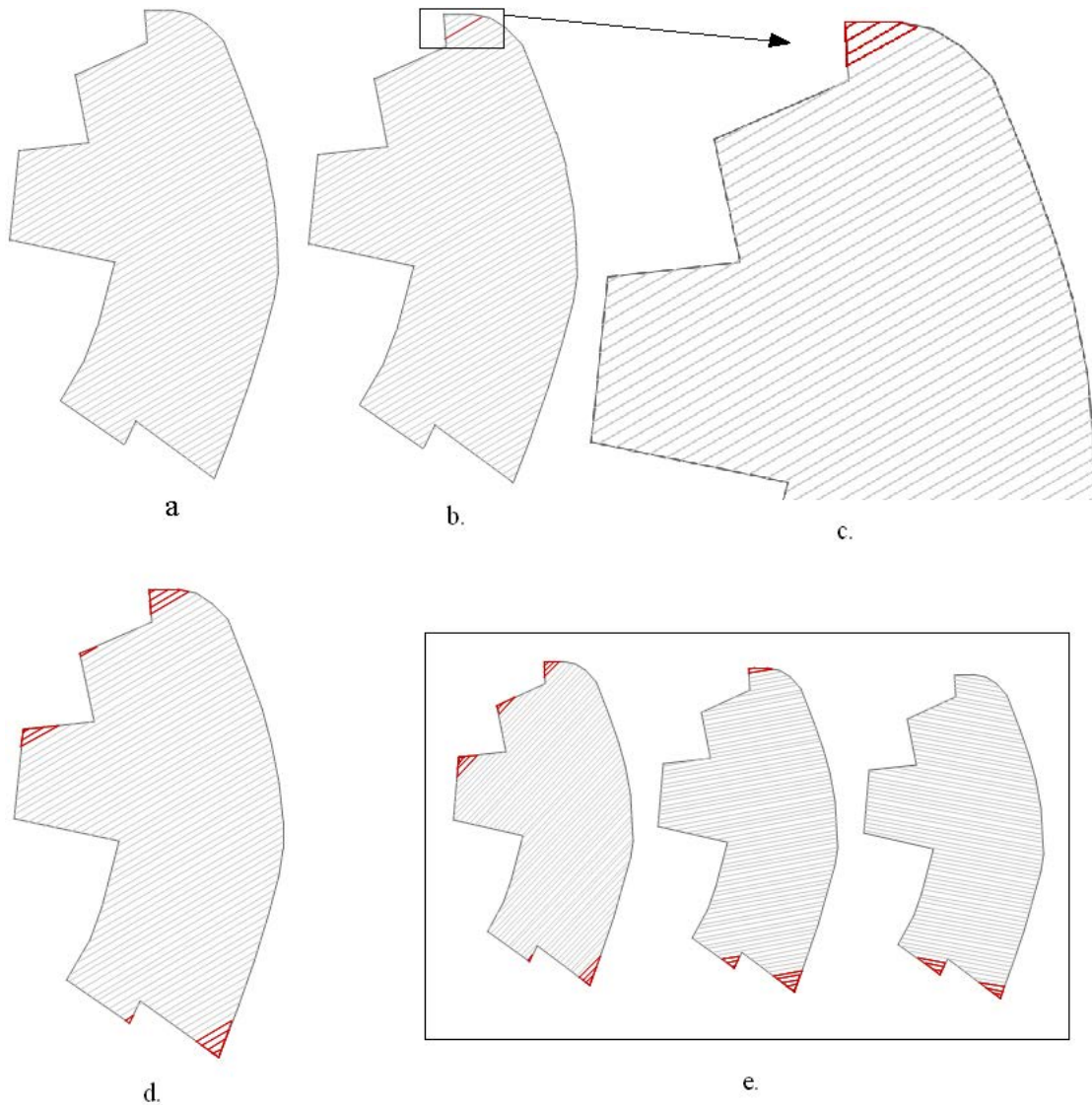
Fig. 3. Example of stepwise results of the processes in the algorithm.

Split field from track

All tracks have two edges intersecting with the field boundary and, for each of the tracks created the algorithm splits the field from these intersections (Fig. 3b) separating a smaller sub-field from the main field. Afterwards the tracks located in the sub-field are identified (Fig. 3c).

Calculate suitability for machine traffic

Suitability based in minimum length

The total length and number of tracks that were identified in the sub-field are retrieved and the average length of the tracks is calculated. The conditions that declare if the tracks inside the sub-field are suitable for operation are:

Minimum track length ≥ Length of the splitting track
AND
Minimum track length ≥ Average of the track lengths located in the sub-field

If the conditions are satisfied, the tracks identified by the algorithm are discriminated for working (Figure 3c) and the respective area covered by these tracks define an uncropped area.

In case that the track length is shorter than the minimum track length, but the average of the tracks inside the sub-field is still longer than it, the respective track is located in a narrow "strangled" region of the fields shape but not in a corner, and the tracks inside them should still be worked. That's why a second condition is herein adopted.

Suitability based on minimum area

The smaller sub-field must have a minimum area to be worked, otherwise it is classified as an uncropped area and the tracks inside it are discriminated for working (Figure 3c).

After the sub-field is classified, the algorithm loops into the next parallel track repeating the steps "b" and "c" until all tracks are classified to be worked or discriminated (as in Fig. 3d). Working impacts retrieved are: the total number of tracks (which equals to the number of turns) the number of avoided tracks, the non-cropped area, the overlapped area of all the tracks and the potential overlapped area of the non-cropped area. The overlapped area is calculated only for the edge of the track as is shown previously in Figure 2.

Looping into another angle

After the classification of tracks is concluded for one angle, its working impacts are retrieved and the algorithm loops into another angle (examples of different angles tried can be seen in Figure 3e). A total of 180 angles are tried (1-180 degrees). For each of the angles tried, the working impacts are listed in the worksheet for the selection of the optimized path.

RESULTS AND DISCUSSION

Two case studies were applied in the algorithm with fully mechanized operations. The width of the machine tracks are known, and the calculation of the minimum machine length was based on simple estimation of costs, productivities and prices paid for the crops in order to see the results retrieved by the algorithm.

Sugar-cane case study

A sugar-cane track cost was studied and applied in the algorithm. The parameters herein used (Table 1) are an approach of reality, in a general example.

Table 1. Parameters for the estimation of minimum track length in the case study.

	Sugar-cane implantation		Sugar-cane harvest
Machine hourly cost (US$):	$	90,00	$ 115,00
Maneuver time (s):		180	50
Maneuver cost (US$):	$	4,50	$ 1,60
Maneuver cost per season* (US$)	$	0,90	$ 1,60

Width (m)	1,5
Productivity (ton ha^{-1})	80
Major production costs (US$ ha^{-1})	$ 2.000,00
Price received (US$ ton^{-1})	$ 35,00
Profit (US$ ha^{-1})	$ 800,00
Profit per linear meter (US$ m^{-1})	$ 0,12

Minimum track length (m):   **20,81**

* Sugar cane has to be implanted only once every 5 years,
so the cost of maneuver has to be diluted for each yearly season

    Costs necessary to comply with law for renewal of native vegetation areas, costs of soil compaction (or overrunning of machinery on rows), and costs of overlap (because of short width) were not considered in this case study. Also the hourly cost of the transport inputs (canes for planting) and outputs (canes for the mill) were not computed because they are not direct part of this issue.

    Figure 4 displays an arable field of 8.57ha applied in the algorithm, observe that the field is limited to a natural reserve shaping a curved border.

200 m

Fig. 4. Arable field located in Mato Grosso do Sul, Brazil.

The working impacts of all the angles can be seen in the graph of Figure 5.
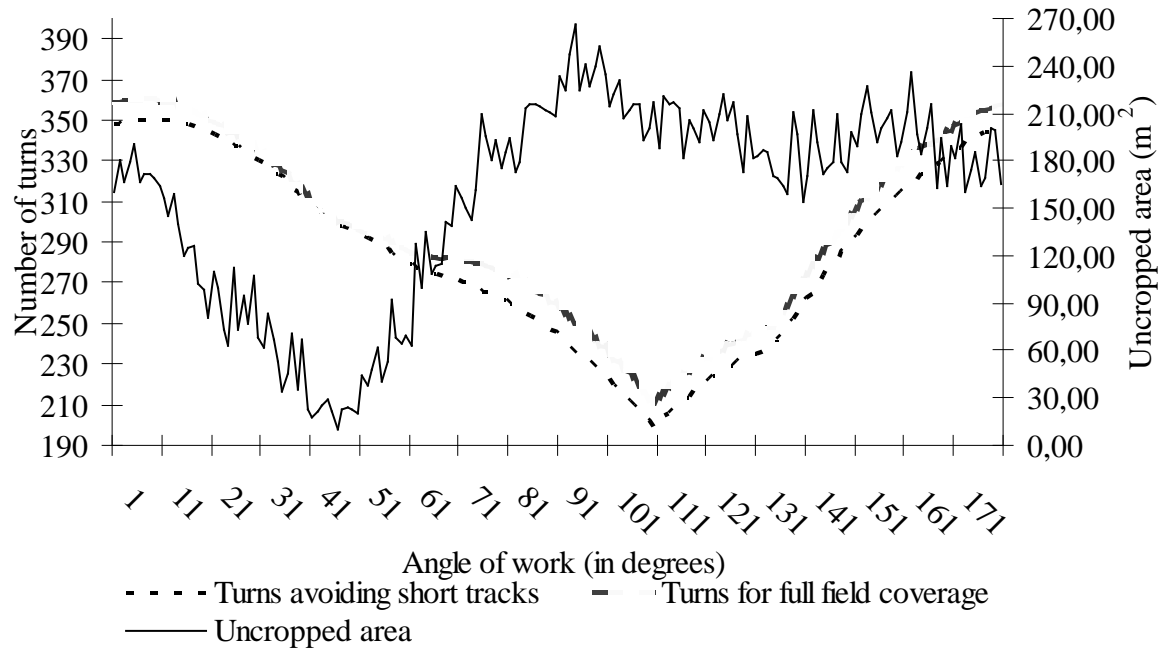

Fig. 5. Graph of the working impacts found for the angles tried (90 degrees is the exact north).
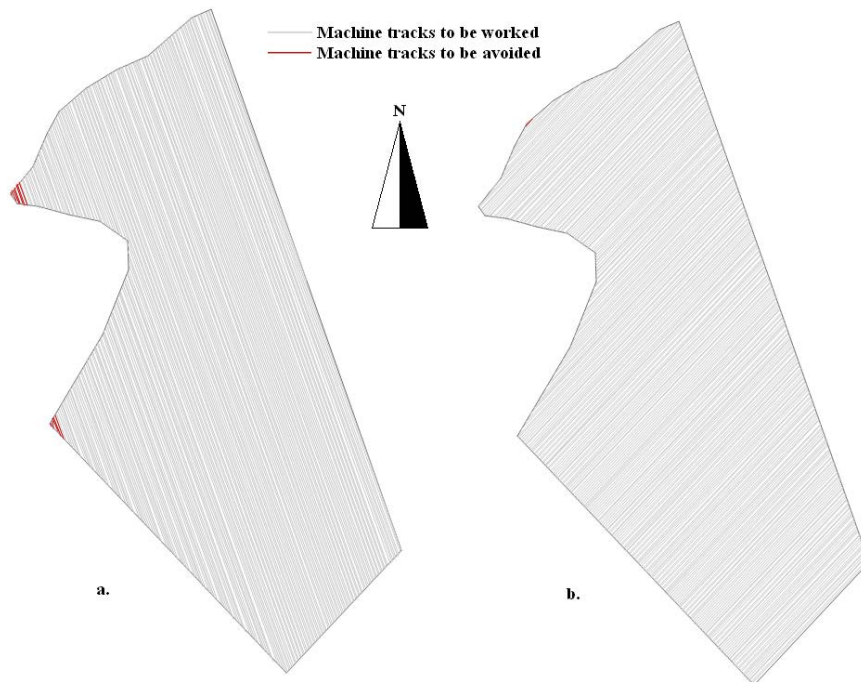

Fig. 6. Selection of two results from the angles tried in the algorithm. Path "a" parallel to the longest field side, and path "b" parallel to the most southern field side.

Figure 6a illustrates the working angle with lowest number of turns as (110 degrees) while Fig. 6b shows the working angle with smallest uncropped area (46 degrees). The optimized path calculated in Fig. 6a, proposes a loss of 0.253% of area with a reduction of 5.69% on the number of turns. This estimation does not consider the kind of turns necessary in these corners, which are almost always more time consuming than turns in perpendicular borders (Jin and Tang, 2010). The path in "b" has 100 more turns than in "a", representing additional 83.3 minutes of turning time.

Corn planting case study

A corn case study was applied to see the impact of selecting minimum worth areas from field corners. Because of the larger width of corn machinery, compared to sugar-cane, the impact of mechanization cost is not so significant for each machine track, so this case study aimed to study the higher impacts for overlap of field operations.

A grain planter with 12m of width was used in the study. Figure 7 displays the arable field of 100.76ha applied in the algorithm for this case study. The field is limited in two curved borders by natural landscape. The minimum area defined as worth for traffic was of 5000 m².
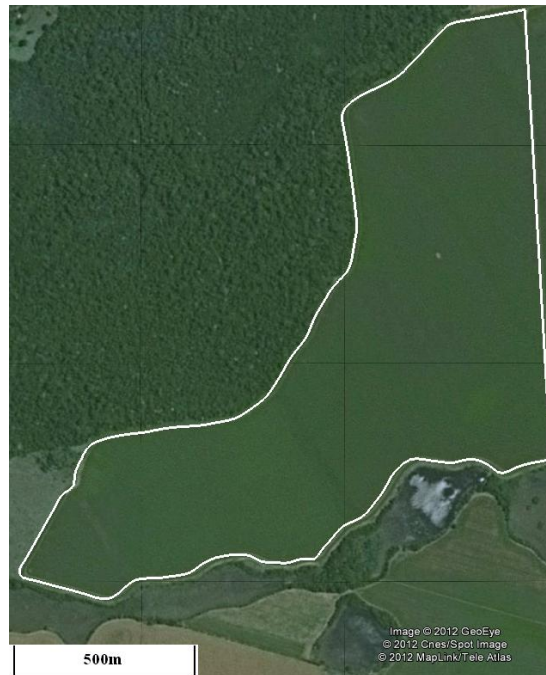

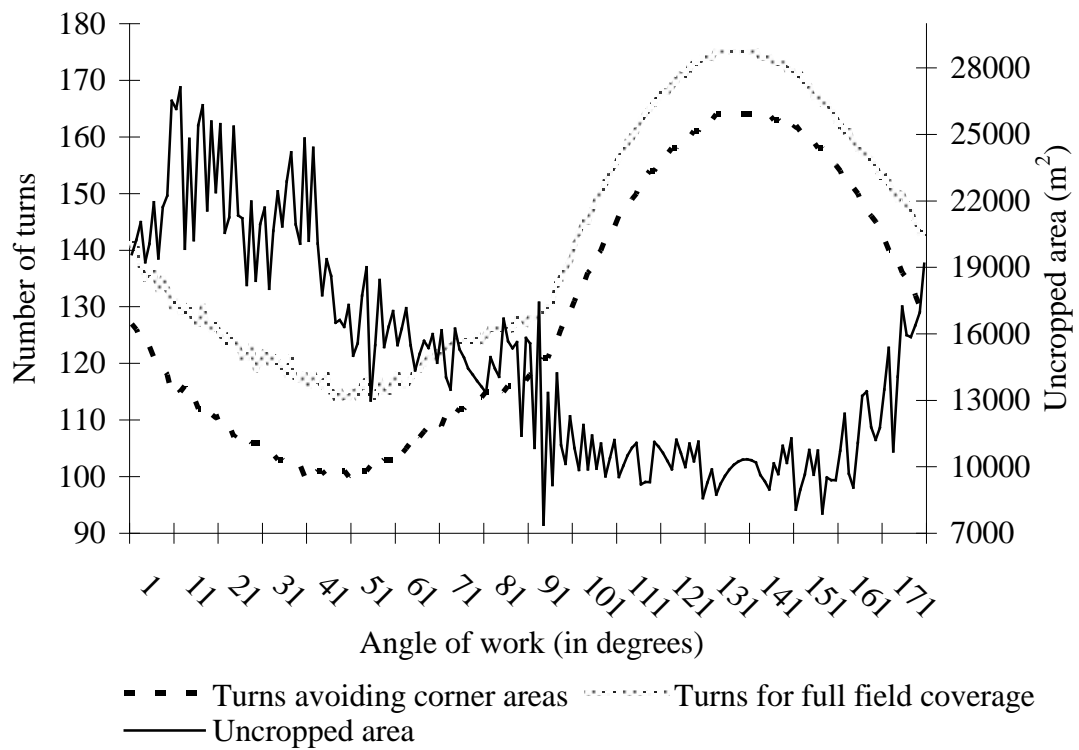**Fig. 7. Arable field located in Mato Grosso do Sul, Brazil.**

Fig. 8. Range of the working impacts found for the angles tried.

The algorithm suggested an optimized path (Fig. 9) that reduces the number of turns in 15,25% towards farming the whole field, with a loss as uncropped area of 2.44 ha (or 2,43% of the total area).
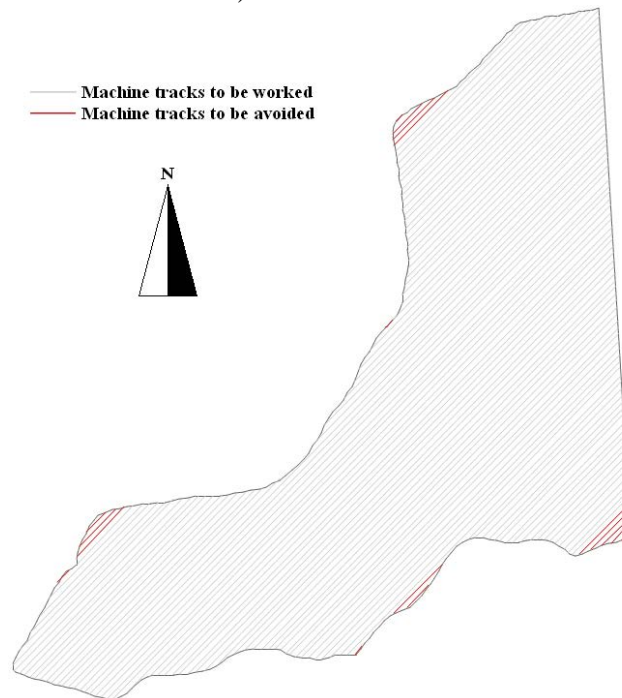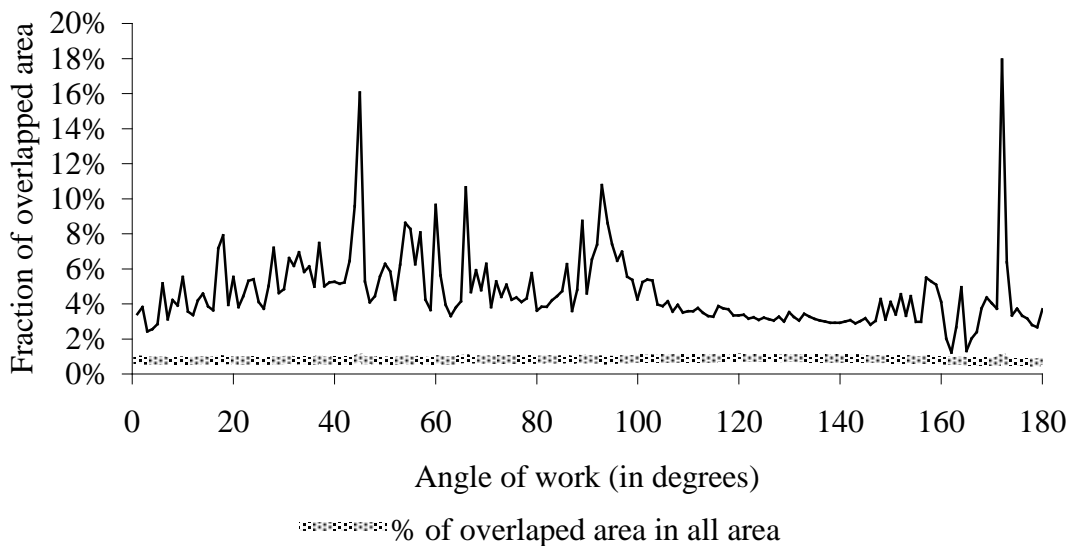

Fig. 9. Optimized path found by the algorithm.

Fig. 10. Graph of proportion of overlap of machinery operations in the whole field in comparison to the recommended avoided areas in the case study.

In the optimized path found (Fig. 9), 16,06% of the uncropped area correspond to overlapped area (see Fig. 10). Despite proportion of overlap area specifically pikes for the optimized path, the amount of overlapped area in avoided field is considerably higher in comparison to the whole field (3.12 times higher in average of all working directions).

In both case studies, apparently no strong relation was found between the number of turns and the loss of area by unprofitable tracks, the impacts of both depends on each case study.

The algorithm is still limited in working only for straight tracks and not able to retrieve of small areas between field and obstacles. Machine tracks also need to be offset on the simulations to optimize the overlap of operations, and the overlap in the margins of a track being covered still have to be added (and nor only the overlap of headlands).

Further work is still needed to combine overlap and turning costs for avoiding corner areas, the corn planting case study only pointed out the impacts for estimating a minimum corner area. Also studies are needed combining the impact of more machinery operations for controlled traffic farming conditions.

CONCLUSION

This work stressed the economical and environmental impacts of machine working in small corner areas and suggests a method that is capable to identify such areas in fields by the use of classifying thresholds than can be calculated. The method was applied in an algorithm capable of creating machine tracks in fields of different shapes and sizes and returns the working impacts of these scenarios. Two case studies with specific machinery impacts were applied in the algorithm retrieving georeferenced machine tracks with minimized working impacts.

REFERENCES

Bochtis, D.D., and S.G. Vougioukas. 2008. Minimising the non -working distance travelled by machines operating in a headland field pattern. Biosystems Engineering, 101(1), 1 e 12.

Brasil. Código Florestal Brasileiro [Brazilian Forestry Code]. Lei Federal n. 4.771, 15 of september 1965.

de Bruin, S., P. Lerink, A. Klompe, T. van der Wal, S. Heijting. 2009. Spatial optimisation of cropped swaths and field margins using GIS . Computers and Electronics in Agriculture, 68,185e 190.

Delalibera, H.C., P.H. Weirich Neto, A.R.C. Lopes, C.H. Rocha. 2008. Alocação de reserva legal em propriedades rurais: Do cartesiano ao holístico [Legal reserve allocation in rural properties: From the cartesian to the holistic]. Revista Brasileira de Engenharia Agrícola e Ambiental v.12, n.3, p.286–292

Hofstee, J.W.; L.E.E.M. Spätjens; H. Ijken. 2009. Optimal path planning for field operations. In: Proceedings of the 7th European Conference on Precision Agriculture. Wageningen Academic Publishers, The Netherlands, pp. 511-519.

Jin, J., and L.Tang. 2006. Optimal path planning for arable farming. Paper no 061158. ASABE, St Joseph, MI, USA.

Jin, J., and L. Tang. 2010. Optimal coverage path planning for arable farming on 2d surfaces. Paper no 097274. ASABE, St Joseph, MI, USA.

Kutzbach, H.D., 2000. Trends in power and machinery. Journal of Agricultural Engi-neering Research 76 (3), 237–247.

Oksanen, T, and A. Visala. 2007. Path planning algorithms for agricultural machines. Agricultural Engineering International, The CIGR EJournal, Volume IX.

Sørensen, C.G., and D.D. Bochtis. 2010. Conceptual model of fleet management in agriculture. Biosystems Engineering, 105(1), 41 e 50.

Spekken, M., and S. de Bruin. Optimizing routes on Agricultural fields minimizing maneuvering and servicing time, Major thesis, may 2010. Wageningen University.

Witney, B. 1996. Choosing and Using Farm Machines (Book). Land Technology, Edinburgh, UK.