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A DSS for planning of soil-sensitive field operations

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A B S T R A C T

The current increased size of agricultural vehicles aggravates the problem of soil compaction causing increased energy requirements, increased CO_2 emissions, and reduced yields. The aim of this paper was to develop a DSS for optimize route planning in terms of minimized risk for soil compaction for agricultural vehicles carrying time-depended loads. The developed system uses as input field and operational characteristics, including a potential risk indicator map based on specific measure of distributed soil physical–chemical properties. It provides the optimal field-work tracks traversal sequence which can be executed using state-of-the-art auto-steering and navigation-aiding systems available on modern agricultural vehicles. The system has been demonstrated and tested for heavy application units used for organic fertilizer. The risk factor was reduced up to 61% by using the corresponding optimal plans instead of the non-optimal conventional ones that an operator would follow.

1. Introduction

The structural development within agriculture, as well as the external demands imposed on agriculture, requires that new knowledge intensive technology including knowledge management become an integral part of environmental-friendly. Therefore, there is a need for innovation and technological development, which can contribute to an efficient utilization of applied resources while at the same maintain the overall sustainability of agriculture. In the current situation, the focus is improved resource utilization and environmental impact and this requires improved process control and other aspects of automation. At the same time, the biology has to be fully integrated in the new technology.

A number of technological foresights have recommended multidisciplinary efforts matching the technical potentials with the prevailing production challenges and user requirements. The research efforts is aimed at a system perspective, where the development and implementation of automation is looked upon from multiple perspectives like energy, environment, management, mechanization system, etc. as well as a clear understanding that the industrial automation process and the biological bio-production are distinctly different. In this regard, it becomes important to define the production challenges which the new technology must meet. A number of decision support systems aimed at supporting the manager meeting the challenges facing agriculture including demands for reduced resource inputs, cleaner production methods, reduced environmental impact, maintaining quality products, etc. [16,18].

One of the main specific challenges is to sustain the soil as growth medium. Soil compaction is one factor that deteriorates soil quality as a growth medium [22]. With the continued increase of size of farm machinery, the problem of soil compaction is aggravated causing increased power and energy requirements, increased CO_2 emissions, difficulties in seedbed preparation, plants emergence, plants growth during the growing season, and reduced yields. Topsoil compaction is mainly influenced by the magnitude of contact stresses and without any mechanical tillage, topsoil compaction effects may last for up to 5 years [15]. Subsoil compaction, on the other hand, is mostly related to the magnitude of wheel load. In the upper subsoil (25–40 cm), the natural recovery from compaction is very slow if it occurs, while the compaction below 40 cm is considered as persistent [1] leading to long-term yield reduction [12].

The continuous increase in the weight of field machines and the necessity to use these machines in un-favorable soil conditions due to timeliness related cost have increased the potential for soil compaction. Combine harvesters of more than 30 Mg and organic fertilizing tankers of 35 Mg is a common occurrence in field operations. Fully loaded, the weight of two-axle sugar beet harvesters is about 35–40 Mg and the weight of three-axle harvester up to 50 Mg. Fig. 1 shows an illustrative example of a damaged field area caused by a heavy agricultural vehicle travelled over an area sensitive to soil compaction.

Current research studies indicate that it is important to effectively control the mechanical impacts of agricultural machinery on soil structure in order to reduce the risk of soil compaction [14]. A number of preventive strategies have been reported [7,22] involving, for example, the control of wheel/track loads and the use of low tire inflation pressures in order to adjust the machines and equipment used in critical conditions to be aligned with the actual strength of

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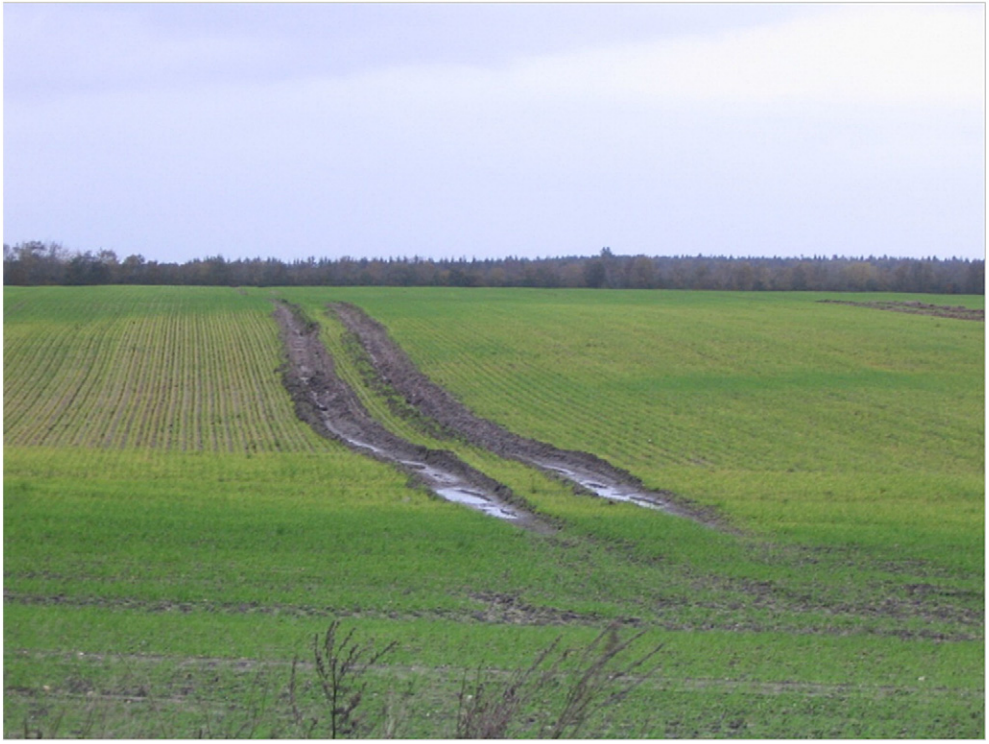

Fig. 1. Damaged soil as a result of unsuitable combination of trafficked track and vehicle load.

the subsoil. Other measures have included the establishment of recommendations for wheel load-ground contact pressure combinations in different soil conditions, guidelines for working at the most appropriate soil moisture content, targeted loosening of both topsoil and subsoil, the use of low ground pressure equipment, etc. Nevertheless, these measures are often compromised by inherent cost constraints. As for example, the alignment of the machinery size with the soil strength capability might require the use of a small-sized, and consequently low capacity, machine which results in increased timeliness and labor cost, as well as increased unit machinery cost.

In order to extend the current preventing measures to integrate and comply with the cost constraints mentioned above, there is a need for researching planning tools involving optimization of the field traffic, in terms of route planning, under the criterion of the minimization of risk on soil compaction.

Field traffic planning for agricultural vehicles has to be addressed as two distinct problems. The first problem regards the generation of the traffic lines (field-work tracks) and is related to the representation of the field as a geometrical entity. A number of methods dealing with this problem have been developed recently (e.g., [9,11,13,17]). The second problem regards the optimization of the routing or motion of the vehicles within this geometrically defined world. In relation to this problem, advanced methods based on combinatorial optimization have recently been introduced. A new type of algorithmically-computed optimal fieldwork patterns, the B-patterns, has been recently introduced [2] providing the optimal field-work track sequencing according to one or more criterions. B-patterns are based on an approach according to which the field coverage is expressed as the traversal of a weighted graph, and the problem of finding optimal traversal sequences of field-work tracks is equivalent to finding the shortest tours in the graph. The weight of the graph arcs could be based on any relative optimization criterion, such as, total or non-working travelled distance, total or non-productive operational time, a soil compaction measure, etc. Contrary to any traditional field-work pattern, B-patterns do not follow the repetition of standard motifs but they are the unique result of the optimization approach on the specific combination of the mobile unit kinematics and dimensions, the operating width, the field shape, and the optimization/s criterion/s. The implementation of B-patterns for autonomous [5] and conventional agricultural machines supported by auto-steering systems [4] showed that, under the criterion of the minimized non-working distance, this distance can be reduced significantly reaching up to 50%. B-patterns can be implemented in the majority of field operations, involving different machinery systems (single or multiple-machinery system) and different operational characteristics (deterministic, stochastic, and dynamic). These patterns can be generated from the implementation of the well-known combinatorial optimization problem, the vehicle routing problem (VRP), after the appropriate abstractive representations of the corresponding routing problems [3].

As mentioned, the pursued approach involve that the resulting optimal traffic pattern consists of sequences of field-work tracks that do not follow any pre-determined standard motif. In contrast, the track sequence is a result of an optimization under a minimization criterion, which makes it feasible to extend and introduce as a criterion the risk for soil compaction for specific types of field operations. These specific field operations are characterized by varying vehicle weight over time during operation execution, e.g. harvesting and tanker application of fertilizer.

The aim of this paper is to present a decision support system for the route planning for agricultural vehicles carrying time-depended loads with the objective of reducing the risk of soil compaction. The principle relies on the basic hypothesis that an area to be worked which has low soil strength, and therefore is more sensitive to compaction, should be worked with a corresponding low vehicle load.

2. System description

The proposed system is targeted toward input material flow field operations where a specific quantity of a material is transported by the agricultural vehicle and is subsequently distributed over the