BIOSYSTEMS ENGINEERING 144 (2016) 38–51

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/issn/15375110

Research Paper

Assessing the actions of the farm managers to execute field operations at opportune times

Gareth T.C. Edwards [a,*], *Niels Dybro* [b], *Lars J. Munkholm* [c], *Claus G. Sørensen* [a]

[a] *Department of Engineering, Aarhus University, Research Centre Foulum, P.O. Box 50, Blichers Alle 20, 8830 Tjele, Denmark*

[b] *Moline Technology Innovation Center, 1 John Deere Place, Moline, IL 61265, USA*

[c] *Department of Agroecology, Aarhus University, Research Centre Foulum, P.O. Box 50, Blichers Alle 20, 8830 Tjele, Denmark*

ARTICLE INFO

Article history:
Received 11 May 2015
Received in revised form
27 December 2015
Accepted 20 January 2016
Published online 19 February 2016

Keywords:
Operation management
Field readiness
Sustainable farming
Workability
Trafficability

Planning agricultural operations requires an understanding of when fields are ready for operations. However determining a field's readiness is a difficult process that can involve large amounts of data and an experienced farm manager. A consequence of this is that operations are often executed when fields are unready, or partially unready, which can compromise results incurring environmental impacts, decreased yield and increased operational costs. In order to assess timeliness of operations' execution, a new scheme is introduced to quantify the aptitude of farm managers to plan operations.

Two criteria are presented by which the execution of operations can be evaluated as to their exploitation of a field's readiness window. A dataset containing the execution dates of spring and autumn operations on 93 fields in Iowa, USA, over two years, was considered as an example and used to demonstrate how operations' executions can be evaluated. The execution dates were compared with simulated data to gain a measure of how disparate the actual execution was from the ideal execution.

The presented tool is able to evaluate spring operations better than autumn operations as required data was lacking to correctly parameterise the crop model. The evaluation criteria could be used to identify farm managers who require decisional support when planning operations, or as a means of promoting the use of sustainable farming practices.

1. Introduction

The decision of when and where to execute an agricultural operation is a complex choice influenced by many variables (Recio, Rubio, & Criado, 2008). Whereas in the past farm managers have relied upon intrinsic knowledge of their environment, as farms expand or the effects of climate change become more prominent the decision of whether a field is ready for an operation introduces more uncertainties (Cooper, McGechan, & Vinten, 1997). In order to plan

* *Corresponding author.*
E-mail address: Gareth.Edwards@agrsci.dk (G.T.C. Edwards).
http://dx.doi.org/10.1016/j.biosystemseng.2016.01.011

operations to be executed efficiently an understanding of when a field is ready for an operation is needed (Sørensen, Pesonen, et al., 2010). This is also essential if multiple operations are to be planned and scheduled at multiple locations (Edwards & Bochtis, 2013).

Field readiness is a measure of an agricultural field's suitability for a specific operation to be executed on it by a specific machine and produce results within a set of predefined parameters. Field readiness is considered as the conjunction of the trafficability and workability of the field, i.e. for a field to be considered ready it must be both trafficable and workable in regards to the subsequent planned field operation (Edwards, White, Munkholm, Sørensen, & Lamandé, 2016).

Trafficability is defined as the ability of the soil to support and withstand traffic, causing only minimal structural damage (Rounsevell & Jones, 1993). Structural damage within the soil and subsoil is most readily observed as soil compaction, which has been studied in depth to determine methods of detection (Motavalli, Anderson, Pengthamkeerati, & Gantzer, 2003) and methods of prediction (Canillas & Salokhe, 2002; Earl, 1996; Saffih-Hdadi et al., 2009). A rule of thumb was proposed by Schjønning, Lamandé, Keller, Pedersen, and Stettler (2012), which aims to avert subsoil compaction by limiting the amount of stress within the soil profile caused by the application of the load under agricultural vehicles to a maximum of 50 kPa at a depth of 50 cm.

Söhne (1953, 1958) first suggested a simple analytical model describing the stress propagation within the soil profile based on the work of Boussinesq (1885) and Fröhlich (1934). This model has been shown to offer a good description of stress propagation in agricultural soils (Arvidsson and Keller, 2004; Keller et al., 2012; Lamandé & Schjønning, 2011).

Workability is defined as the ability of an operation to be carried out at a specific time to give a positive result (Droogers, Fermont, & Bouma, 1996). The definition is purposely ambiguous as different operations have a specific set of criteria under which their results can be deemed as successful (Sørensen, Fountas, et al., 2010). The workability of tillage is defined as the ability of the soil to produce adequately size aggregates without causing smearing (Rounsevell & Jones, 1993). Dexter and Bird (2001) proposed equations for determining the optimal soil moisture content for tillage in terms of the hydraulic properties of the soil. A range of soil water contents was also defined, with upper and lower limits about the optimal soil moisture content, within which tillage can be executed without causing adverse effects.

The workability for planting a crop relates to the soil temperature at the date of execution and in the following weeks. Saab (2009) states that while there is an optimal soil temperature for seeds during planting, there is also a minimum soil temperature that cannot be breached in the weeks following planting without causing stress to the seed and ultimately affecting the crop yield. Seeders and planters also engage the soil, therefore requiring the soil to be tillable as well. A growing trend in recent years across the U.S. Corn Belt has been to move planting date earlier so as to maximise the growing season (Kucharik, 2008). While this practice aims to increase the yield of the final crop and maximise flexibility when planning the harvest, it runs the risk of planting, and other spring operations, being executed when fields are not ready. As farm operation management practices move away from established actions, the value of a farm manager's inherent knowledge is lost and the need for decision support tools increases.

Executing operations in fields which are not ready can have both short term and long term effects. Soil compaction can have many adverse effects such as reducing the volume of macropores, limiting the transfer of gases and minerals, stunting the development of the crop and decreasing expected yield (Kuncoro, Koga, Satta, & Muto, 2014). A study carried out in Belgium (Nevens & Reheul, 2003) showed a 13.2% loss in the growth of maize as a result of wheel induced compaction on sandy loam soil. Soil compaction can also be very persistent with decreased yields (Alakukku and Elonen, 1995) the effects of soil transportation (Berisso et al., 2012) still being observable after up to 14 years after the soil was first compacted. Longer term effects have also been observed up to 29 years (Schjønning et al., 2013).

Additional operations can be executed on the field to alleviate some soil damage, however these also incur additional operational costs affecting the profitability of the crop. Damage to a standing crop may be alleviated by increased applications of chemicals although this would also increase the production costs as well as possibly effecting the environment too. De Toro (2005) estimated the cost of executing operations when fields were not defined as workable and found that these costs could comprise a significant proportion of the overall variable costs of production, estimated at up to 150€ ha^{-1}.

The untimely execution of operations does not just affect crop profitability, it can also affect the local environment. Soil compaction can limit soil water holding ability, increasing water run off (Fleige & Horn, 2000) and increasing the risk of eutrophication (Smith, Jackson, & Withers, 2001) or localised flooding. If the case of a farmer's management actions affect conditions outside the local farm, regulations are likely to be placed on farmers (Nikkilä, Wiebensohn, Nash, Seilonen, & Koskinen, 2012). Appropriate incentives are therefore essential to encourage sustainable farming practices, although measures will need to be developed to make actions auditable (Tilman, Cassman, Matson, Naylor, & Polasky, 2002).

De Toro and Hansson (2004) presented two methods to evaluate field operations. The first, the *Aver. Work* method, utilised average workday probabilities and a formula for timeliness costs proposed by ASAE Standards (2000). Similar methods utilising average workday probabilities are described in Van Elderen and Kroeze (1994) and Wijngaard (1988). The second method presented in De Toro and Hansson (2004), the *Daily Work* method, used simulated data and assessed the workability of the fields for the operations and the delay from a specific date until the operation was executed. The *Daily work* method was determined to offer a better estimation of the timeliness costs of an operation's execution as it could handle the evaluation of a sequence of operations and utilised a more detailed methodology.

Farm management information systems (FMIS) are used to collect, interpret, report and store data pertaining to farm practices. A conceptual model was represented by Sørensen, Pesonen, et al. (2010) in which system boundaries are defined, dividing the entities within the farm manager's control from those which are outside their control but exerting an effect on the system. The farm managers are seen as an active