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Modelling the readiness of soil for different methods of tillage

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ABSTRACT

While research has been conducted on the workability and trafficability of soils separately, it is the combination of these two factors which allows a decision to be made about a field's readiness for a given operation. Knowledge about when a field is ready for an operation is essential when planning when and where operations should be executed, so that they can be executed in an efficient and cost-effective way. In this paper, methods for evaluating workability and trafficability were combined to produce a novel decision support tool for assessing the readiness of a location for tillage operations over a period of time.

Three soils within a field were examined using the proposed tool to estimate the number of days they were in a state of readiness for conventional tillage and minimum tillage over an 11 year period. The soils were assessed for when they were trafficable, when they were workable and when they were both trafficable and workable. The assessments were made based on the soil texture, simulated soil water content and physical parameters of machines likely to be used for the defined operations.

All of the soils were ready for longer periods of time for minimum tillage than for conventional tillage. During autumn tillage, it was approximately twice as likely that the field would be ready for minimum tillage as it would be ready for conventional tillage. The tool offers the means for comparing operational management decisions either as a standalone tool or as a part of a larger farm management information system.

1. Introduction

The structure of the soil in which a crop is planted significantly influences the quantity and quality of the crop produced. Soil parameters such as available water or nutrient content can be readily quantified and linked to the eventual crop yield (Godwin and Miller, 2003), whereas soil condition is more difficult to quantify (Pikul et al., 2001). The structure of the soil is a key factor and it can often be damaged by excessive loading (Nevens and Reheul, 2003), or by tillage being executed at inopportune times (Keller et al., 2007). To improve the quality of the soil structure during planting, a decision support tool is needed for estimating and evaluating field conditions to ensure tillage operations are executed at opportune times so that the best outcomes are achieved.

To qualify the suitability of soils for tillage and traffic, the term readiness is introduced. The readiness of a soil for an operation is a combination of the workability and trafficability (Rounsevell, 1993), both of which are influenced by the soil properties, the weather, the crop, the operation and the machinery used. The time a field is in a state of readiness for an operation is the window of opportunity. Typically in England fields have a window of opportunity for tillage of a few weeks in autumn and spring. The readiness of a field can be utilised to create efficient schedules for machine operations (Edwards et al., 2013). The costs associated with executing operations when the field is not at an optimum level of readiness account for a large proportion of the annual variable costs a farm manager may incur (De Toro, 2005). The number of days a field might be ready for an operation is also influential when making decisions on fleet sizing and machine capacity, to ensure that there is enough time to execute all operations at all locations within the window of opportunity (Søgaard and Sørensen, 2004).

Included in a 1984 soil survey in England and Wales was an estimation of when different types of soils would be trafficable. This was based on the meteorological estimate of when fields would be at field capacity and a wetness factor for each soil type related to their permeability (Ragg et al., 1984). The methodology assumed the use of machines much smaller than those being used today, so it is hypothesised that the results may no longer be

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applicable to modern practices. Also advances in the research fields have introduced more analytical methods for determining both workability and trafficability which could be utilised.

Trafficability is defined as the ability of soil to support a vehicle while only causing negligible, or reversible, damage (Rounsevell, 1993). Damage to the soil can originate from compaction (an increase in bulk density) or deformation (changes to the structure). Both forms of damage limit the soil's water holding capability, limit the flow of nutrients within the soil and restrict root development, all of which adversely affect the final crop yield (Lipiec and Hatano, 2003). Evaluation of soil trafficability is based on the comparison of stresses applied to the soil and the soil strength. Soil strength and deformation depends on both intrinsic properties (soil texture, mineralogy, content and nature of organic matter) and water content. Bigger tyres, lower inflation pressures and tracks, help to reduce the stress at the tyre/soil interface (Lamandé and Schjønning, 2008). However, as agricultural machines become larger, subsoil layers are still at risk (Lamandé and Schjønning, 2011), which can result in a reduced number of days a field may be trafficable of an operation.

Söhne (1953, 1958) first suggested a simple analytical model for the stress propagation within the soil profile. This model proved to reliably predict the vertical stresses from the contact between the soil and tyre (Keller and Arvidsson 2004; Keller and Lamandé, 2010). Schjønning et al. (2012), proposed the '50–50 rule' which states "at water contents around field capacity, traffic on agricultural soil should not exert vertical stresses in excess of 50 kPa at depths >50 cm". This rule of thumb aims to minimise subsoil compaction which would then be difficult to remediate using conventional techniques. The 50–50 rule introduces a measuring standard by which an operation can be judged acceptable.

Workability is defined as the ability of an operation to be executed within predefined limits for damage and performance quality parameters. In the context of tillage, workability is defined as the ability of the soil to produce an adequate friable tilth in preparation for seeding without causing smearing or compaction (Rounsevell, 1993). Methods to define workability can include both field testing and laboratory analysis.

Earl, (1996) relates measurements using a soil penetrometer to measurements of soil water suction. However only the "wet end" of the soil moisture limit was considered, as under normal UK conditions soil rarely becomes too dry for tillage during spring and autumn. In a later study, Earl (1997), the soil moisture deficit was used to predict the workability and trafficability of soils typical of central and eastern England. A 70 kW (~94 horse power) tractor was considered for the soil trafficability assessment, however now a much larger tractor, approx. 150 horse power, would be used for the operations. For both of these methods the sites must be visited in order to be assessed, which is time consuming and may prove impractical in today's modern agricultural practices.

Dexter and Bird, (2001) defines the optimal soil water content to execute tillage as the soil water content at which tillage produces the greater proportion of small aggregates. When tillage is performed at greater soil water contents large clods can form and smearing can occur. Similarly when tillage is performed at lower soil water contents excessive forces must be employed. This leads to an upper (wet) and a lower (dry) soil water content limit. In between these limits tillage may be executed to produce preferable results and the soil can be defined as workable.

Rounsevell (1993) suggested that if a field is workable then it must be trafficable and that the converse was not necessarily true, however this is an over simplification. Trafficability is a condition related to the vehicle being used and there could be a case when the soil is workable but not trafficable, especially when large vehicles are being used. In this case, smaller machines would have a larger window of opportunity to execute an operation than larger, heavier, machines This would allow smaller machines to have a

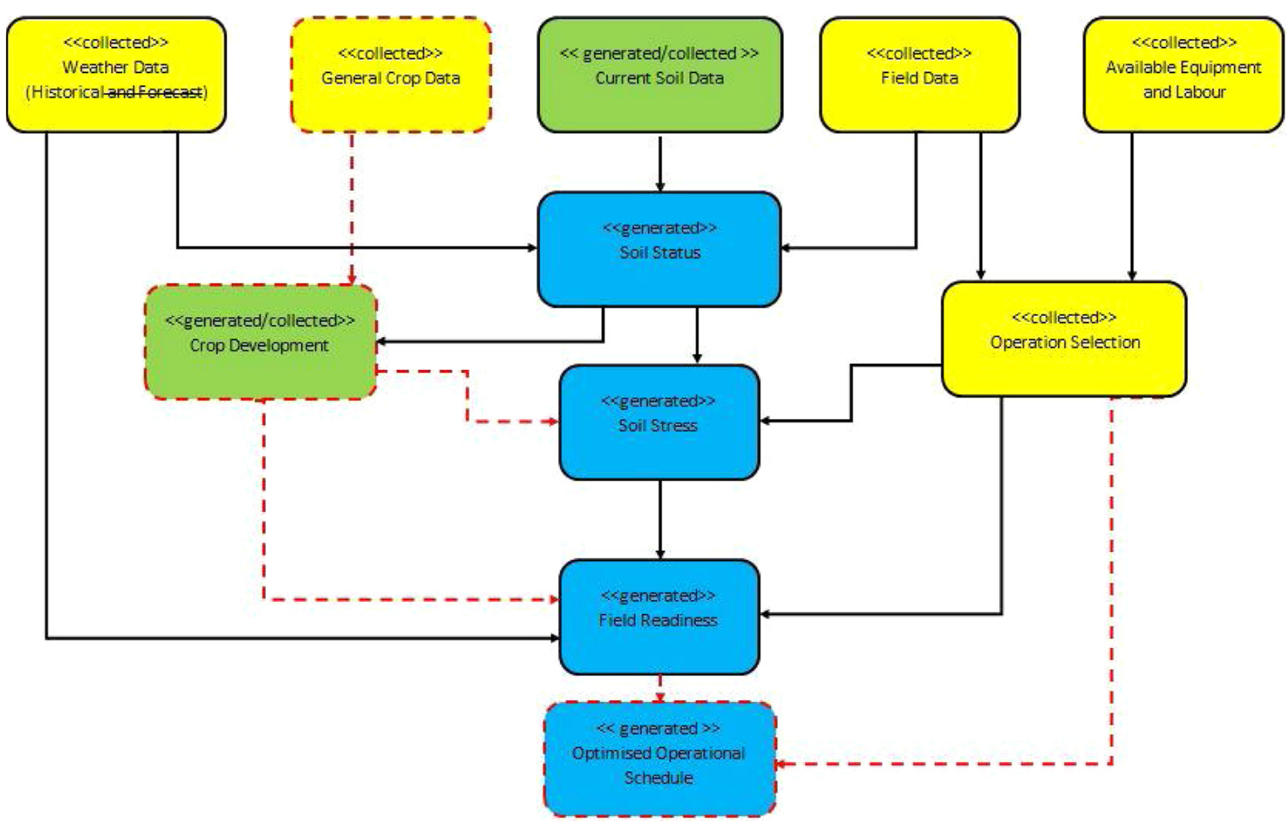

Fig. 1. Tool architecture.