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Terranimo® - A Soil Compaction Model with internationally compatible input options

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ABSTRACT

Soil compaction in agricultural fields, especially in the subsoil, is an increasing problem caused by traffic with heavy machinery, and the damage has proven nearly persistent. Decision support for sustainable traffic is urgently needed. The Terranimo model (www.soilcompaction.eu) simulates the stress distribution in the contact area and down into the soil as inflicted by a tyre with a certain wheel load and inflation pressure. Evaluation of the compaction risk is achieved by comparison to soil strength also estimated by the model. The model needs information on machinery, site characteristics, soil texture and soil water content. The machinery data can be selected from a database, where data on machine are stored by country and where tyre data are stored in general tables. The user can supply input on soil texture and soil water both manually and by automatic methods, which can utilise country-specific soil and weather databases. State-of-the-art models are implemented for simulation of stress distribution in the contact area and the vertical stress in the soil profile. Only the vertical stress component is dealt with in this first version of Terranimo. Soil strength is calculated from soil clay content and soil matric potential by equations derived from new data on soil precompression stress. Model outputs are presented as charts. Contact stress is shown in a 3D surface or contour plot. Soil stress in the soil profile is shown as contour plots with stress isobars. The present version of the Terranimo tool is considered valuable for farmers, contractors and agricultural consultants to show the effects of machines and soil characteristics on stress propagation and soil strength and to evaluate soil compaction risk. The tool is prepared for worldwide extension depending on the availability and the possibility to access national soil and weather databases.

Keywords: Soil, compaction, model, internet, Denmark, Finland, Switzerland.

1. INTRODUCTION

Modern agriculture poses high stresses to the soil. The loads from the machines may induce stresses exceeding the strength of the soil causing soil compaction. This reduces the volume, size distribution and continuity of soil pores (Berisso et al., 2013) which may increase the environmental loading like erosion and greenhouse gas emissions due

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to reduced water infiltration and gas diffusion (e.g. Soane and van Ouwerkerk 1995). Soil compaction may also reduce crop yields (Håkansson and Reeder, 1994). There is a need to improve farmers' opportunity to predict and evaluate the risk of soil compaction to avoid harmful consequences due to compaction, and to evaluate the effects of different technical solutions on the risk of compaction. In essence, this requires a quantitative comparison of stresses exerted by machinery and the mechanical strength of the soil.

Soil strength is determined by soil characteristics, primarily the soil textural composition and the soil water content. Data on soil characteristics and climatic conditions across large areas are now available in digital form, which thus enables an estimate of soil strength for a given soil at a given date. The mechanical stresses from wheels can be estimated from characteristics of the tyre, and the distribution of stresses in the soil profile can be modelled.

An international group ('PredICTor' project) funded by the European Commission's ERA-NET "Coordination of European Research within ICT and Robotics in Agriculture and Related Environmental Issues" (ICT-AGRI) under the 7th Framework Programme for Research have prepared a web-based tool named Terranimo (Terramechanical model). This paper describes the Terranimo system with special emphasis on the input facilities, the model, the system-internal database, and the communication with external databases.

2. SYSTEM DESCRIPTION

Terranimo is designed with three separate components (Figure 1): Database, Model and User interface. Each component can be implemented on different servers. Terranimo also makes use of an external model for calculation of soil water content and country-specific soil and weather databases.

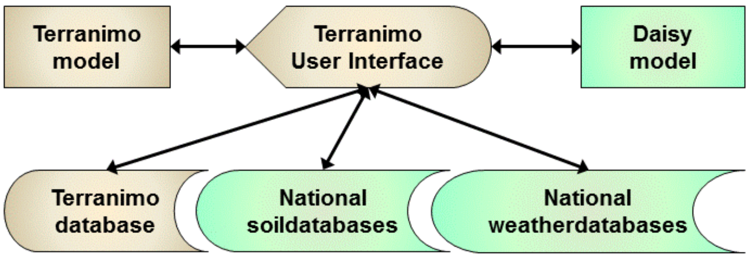


Figure 1. Terranimo system components (model, user interface and database), the external model and national databases and the interactions between them.

Terranimo is implemented as a web application using Microsoft Visual Studio 2010, Telerik RadControls for ASP.NET AJAX for additional controls and ChartDirector for graphical presentations. Microsoft SQL Server 2008 R2 is used as data storage.

Terranimo is available in an international and – at present – three country-specific versions. The international version is activated from the website www.soilcompaction.eu, while Danish, Swiss and Finnish versions are run from .dk, .ch and .fi websites, respectively. The country-specific versions deviate from each other as described in the following. All versions of Terranimo can be run with the following languages: English, Danish, Finnish, German and French.

2.1 Input in user interface

There are two tab pages for input in the user interface: one for machinery and one for site information. Two other tabs provide output from the calculations (see section 2.4). The system allows the user to make inputs in either order and is designed to keep track of the most recent inputs. Default values of input values are provided, which means that a direct access to the output tabs creates results for these pre-selected combinations of machinery and site characteristics.

2.1.1 Machinery

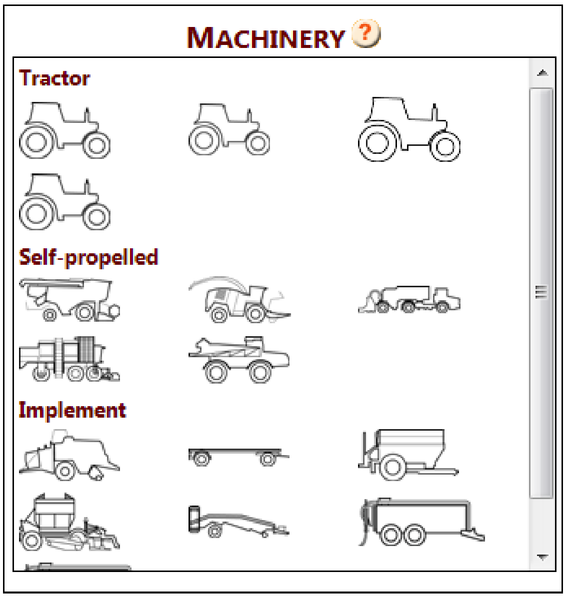


Figure 2. Panel for selecting machinery.

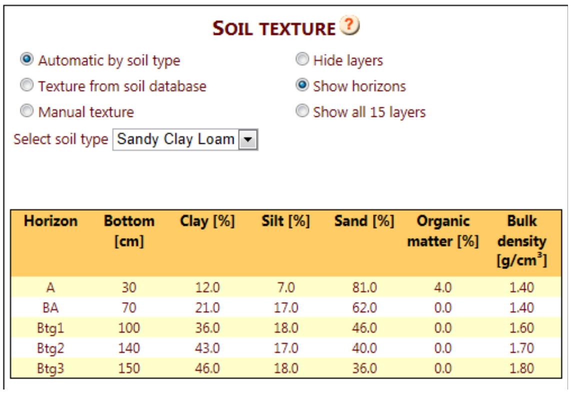
The panel with icons of machines reflects the content in the Terranimo database, where data on machinery is defined in tables for machines, axles and wheels. The data are country specific, which means that the user will be met with machinery options typically used in each country. The machines are divided into three categories: Tractors, self-propelled machines, and implements. The user can select a tractor combined with one implement or select a self-propelled machine. Each wheel on a machine can be equipped with a tyre from the database, and each tyre can be inflated to the desired tyre pressure and exposed to the desired load.

2.1.2 Site information

On the tab page for site information basic data can be entered. Latitude/longitude of a location may be input for automatic access to external databases on soil and weather (see section 3). The crop grown at the given location may similarly be input for the purpose of model-calculation of soil water content (see section 3).

2.1.3 Soil texture

The system gives three possibilities for obtaining soil texture (Figure 3).



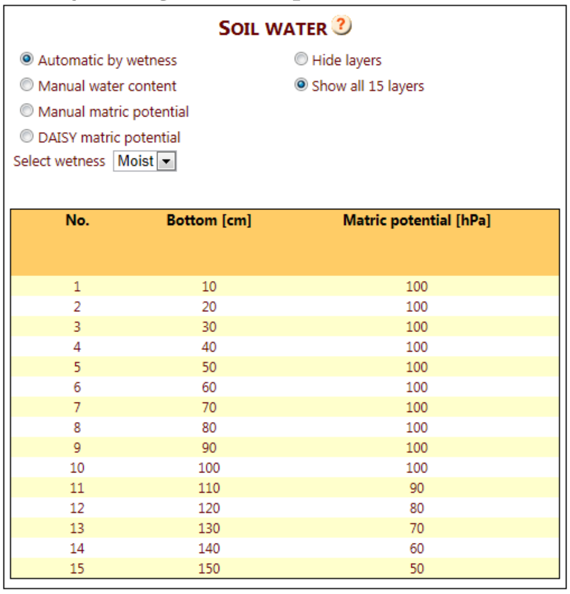
Horizon	Bottom [cm]	Clay [%]	Silt [%]	Sand [%]	Organic matter [%]	Bulk density [g/cm^3]
A	30	12.0	7.0	81.0	4.0	1.40
BA	70	21.0	17.0	62.0	0.0	1.40
Btg1	100	36.0	18.0	46.0	0.0	1.60
Btg2	140	43.0	17.0	40.0	0.0	1.70
Btg3	150	46.0	18.0	36.0	0.0	1.80

Figure 3. Panel for selecting soil texture.

1. The default option is ‘Automatic by soil type’. For each country a set of predefined soil types is available in the Terranimo database. Each of these types are characterised by fractions of clay, silt and sand, by organic matter and by bulk density for a number of horizons.
2. An alternative method for obtaining soil texture is by accessing national soil databases (see section 3).
3. The option for ‘Manual texture’ allows the user to input soil texture for his own specific field in case data is available.

2.1.4 Soil water

The system gives four possibilities for obtaining soil water data (Figure 4).



No.	Bottom [cm]	Matric potential [hPa]
1	10	100
2	20	100
3	30	100
4	40	100
5	50	100
6	60	100
7	70	100
8	80	100
9	90	100
10	100	100
11	110	90
12	120	80
13	130	70
14	140	60
15	150	50

Figure 4. Panel for selecting soil water.

1. The default option is ‘Automatic by wetness’. Three different water regimes are defined: ‘Wet’, ‘Moist’ and ‘Dry’.
2. The user may input measured gravimetric water contents for the specific soil in question. Terranimo will then calculate the corresponding matric potential from soil texture (Wösten et al., 1999).
3. The matric potential for a soil (e.g., measured with tensiometer) can be entered manually.
4. The system also offers the option of calculating the matric potential by using a soil-plant-atmosphere- continuum model (see section 3).

2.2 Model

The Terranimo model is implemented as three object-oriented classes (Table 1). The model can be directly linked into the user interface by the development environment, but the model can also be implemented as a web service and hence be used by other external applications.

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Table 1. Methods in the Terranimo model.

Model class	Method	Input	Return
Contact stress	CalculateFridaParametersStd	Tyre data	array of x/y pairs
	CalculateFridaParametersSpec	Tyre data, soil data	array of x/y pairs
	CalculateVerticalContactStress	FRIDA data, wheel load	2 dim. x/y array
Soil stress	CalculateConcentrationFactor	Soil wetness	Decimal value
	CalculateVerticalSoilStress	Concentration factor, Contact stress	2 dim. y/z array
Soil strength	CalculateSoilStrength	Soil data	Decimal value

2.2.1 Contact stress model

The function CalculateVerticalContactStress calculates the vertical stress in the tyre-soil contact area by use of the so-called FRIDA model (Keller, 2005; Schjønning et al., 2008). The return value is a two-dimensional array in an x/y plan. The functions CalculateFridaParametersStd and CalculateFridaParametersSpec parameterize the FRIDA model from tyre characteristics, the tyre inflation pressure and the wheel load. CalculateFridaParametersStd provides estimates for a ‘standard’ soil, which in Terranimo is defined as a sandy loam soil (Schjønning et al., 2006). These estimates are used for displaying wheel load and tyre inflation pressure effects for individual wheels. The CalculateFridaParametersSpec function is identical to the Calculate-FridaParametersStd except that it incorporates topsoil consistency effects on the FRIDA parameters (yet unpublished). Terranimo results displayed in the output tabs are based on the latter.

2.2.2 Soil stress model

The function CalculateConcentrationFactor returns a value, which is dependent on the soil matric potential. It takes values between 6 (‘wet’ soil) and 4 (‘dry’ soil). The function CalculateVerticalSoilStress calculates the vertical stress in the soil profile (Söhne, 1953). The return value is a two-dimensional array in a y/z plan.

2.2.3 Soil strength model

The function CalculateSoilStrength gives an estimate of the soil strength. First, precompression stress is calculated with a pedotransfer function including soil content of clay and the matric potential (unpublished data). Next, the precompression stress is scaled to yield a value of 50 kPa at a matric potential of -100 hPa as based on data by Keller et al. (2012).

2.3 Terranimo database

The database contains tables grouped around machinery (Figure 5) and soil (Figure 6).

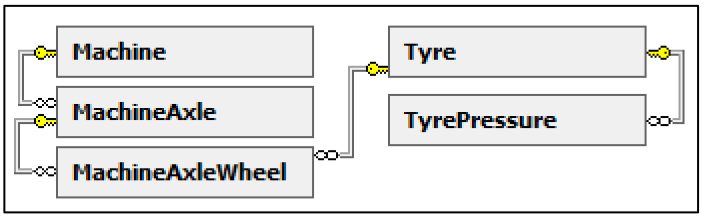

Figure 5. ER-diagram of machinery data tables.

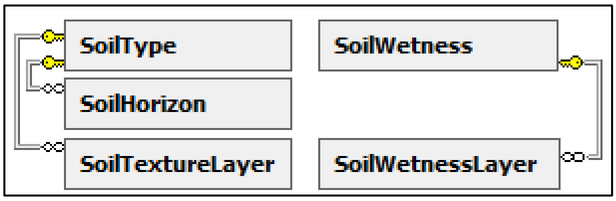

Figure 6. ER-diagram of soil data tables.

The data in the machinery tables are stored with one-to-many relations between machine and axle and also between axle and wheel. This allows for positioning all the wheels in an overall x/y-plane, which is important for correct predictions of vertical stress in the soil profile by the CalculateVerticalSoilStress method (including interaction between the stresses deriving from neighbouring tyres). A tyre is related to each wheel and each tyre has a relation to a set of pressure data in order to estimate recommended load.

The data on soil type has one-to-many relations to both soil horizons and soil layers. Similar the soil wetness has a one-to-many relation to soil wetness layer. Soil type and soil wetness gives the possibility to have predefined setups of fifteen 10 cm layers for input to the Terranimo model.

Both data on machinery and soil are stored with a country ID, which facilitates the use of country specific web sites.

2.4 Output in user interface

The results from the model calculations are presented in two set of graphics: Contact stress is shown in a 3D surface or contour plot. Soil stress in the soil profile is shown as contour plots with stress isobars (pressure bulbs). It is beyond the scope of this paper to discuss the detailed outputs. Here, we choose to show another option also available to the user: a display of tyre-soil contact area, contact area stress, and the distribution of vertical stress in the soil profile for one specific tyre (Figure 7). This summarizing graph is valid for a ‘standard’ soil and allows the user to have a quick evaluation of the effects of changing tyres, tyre inflation pressure, and wheel load.

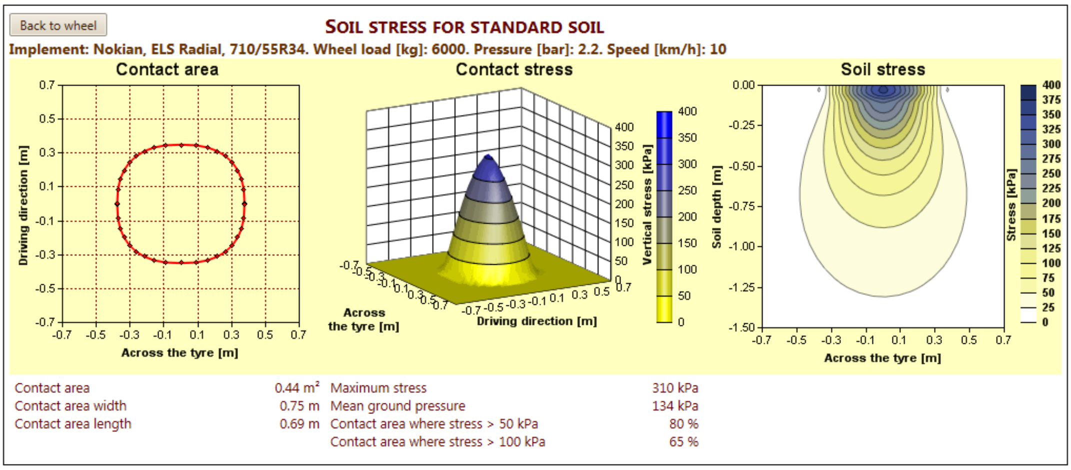

Figure 7.Tyre-soil contact area (left), contact area stress (middle), and stress in the soil profile (right). Calculated for standard soil.

3. EXTERNAL COMMUNICATION

An important feature of the Terranimo decision support tool is the possibility of creating immediate access to geo-referenced electronic data bases on soil characteristics and weather properties. Access to these country specific databases is facilitated through web services on a national server. These web services are built on a common template, in order to secure standardised input and output. This provides the opportunity for any user within a given geographical region to have simulations of the soil compaction risk that is optimized for the specific location of the user. At present (May 2013), automatic access to data bases has been implemented for Denmark. Work is in progress to establish similar access for Finland and Switzerland, and the system is open to include any country that can provide the needed data bases. Access to Google Maps has been implemented for providing location coordinates, which are then used as an identifier for reading the data bases.

The data returned from the soil data bases includes clay, silt, sand and organic matter content as well as soil bulk density given for up to 15 horizons.

The DAISY (Abrahamsen and Hansen, 2000) model can be used for estimating matric potential in soil layers. The input for the model for this use is soil texture, crop, and weather data eight months back in time. The model software is installed on the server that also runs the user interface. The soil texture and crop is supplied from the user interface, while weather data (precipitation, global radiation, temperature and evaporation in daily values) is downloaded by accessing web services connected to national weather databases from the user interface and then supplied for the DAISY model.

4. DISCUSSION AND PERSPECTIVE

Many European soils are highly vulnerable to soil compaction (e.g., van Camp et al., 2004), and there is an urgent need to create an operational tool to help different stakeholders to identify the unsuitable field traffic situations and the risk of (sub)soil compaction at different conditions. Terranimo provides a tool for that purpose. It utilizes the country-specific databases or allows the user to input specific data for soil conditions. The tool is made freely available for farmers, machine/tyre manufactures, policy-makers, and other stakeholders interested in the soil compaction problem.

One strength of Terranimo is the possibility of simulating stresses from a range of different machines and in particular the effects of tyre type, tyre inflation pressure and wheel load. The most recent knowledge on soil stress inflicted from loaded tyres, on stress transmission in the soil profile, and on soil strength for different soil textures and water contents is implemented in the system. The further development of the tool should include optimized output modules in terms of enhanced graphics, user-friendly advice in text blocks as well as output of results in numbers.

The Terranimo tool is seen as a first step along a line towards internet-based systems for ‘on-site’ decisions on traffic in order to avoid compaction.

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