ICT-AGRI Call 1 Final Project Report

Acronym

PredICTor

Title

Preparing for the EU Soil Framework Directive by optimal use of Information and Communication Technology across Europe

Consortium

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Final publishable summary report

Final publishable summary report of the key findings and impacts written for a non-technical audience, which ICT-AGRI may use to communicate results to user. It should also be possible to use in national reporting (1 A4 page, font size 12).

Our soils are under threat. The EU Commission has planned a Soil Framework Directive addressing how to protect soils from degradation. Compaction of soil from agricultural machinery is identified as one of eight major threats. The compaction process is complicated as it is dependent on characteristics of the machinery (tyres) as well as soil properties. Recent research has, nevertheless, increased our knowledge to a level that enables predictions on the compaction risk for an intended traffic with given machinery on a given soil.

Research groups from Denmark, Switzerland and Finland formed a consortium ‘PredICTor’ 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. Research groups from Germany and The Netherlands participated as project consultants without ICT-AGRI funding. The purpose of the project was to provide decision support tools for evaluating and hence reducing soil compaction. The PredICTor project aimed at two deliverables: i) an online, interactive decision support system labelled Terranimo, and ii) European-wide maps of the wheel load carrying capacity (WLCC).

The Terranimo online tool can be accessed from www.soilcompaction.eu and enables any user worldwide to predict the risk of compaction for any specific combination of soil and machinery. Machinery is selected from a list of typically used machines, and tyre type, wheel load and tyre inflation pressure can be set to match the traffic situation of the particular user. Soil type and soil water regime are chosen either by selecting among typical default scenarios or by user input. The system is prepared for input of soil data from national databases through GoogleMaps identification of geographical coordinates. It is also possible to calculate soil water by a crop model through the access to weather databases.

Terranimo provides its results for the user by comparing soil stress with soil strength for each wheel of the machinery selected. Graphic display enables a quick assessment of the sustainability of the planned traffic event. It is possible to evaluate at which depth of the soil profile, traffic is likely to create damage. The idea of the system is to interactively modify machinery and soil conditions for a quick evaluation of the effect on the stress-strength relation.

Terranimo is currently available in four versions each displaying default machinery and soil types relevant for the geographical region in question (international, Denmark, Finland, Switzerland). The system is prepared for easy extension with additional countries. Independent of this, the user can select among five languages: English, German, French, Finnish and Danish. More languages may easily be added. In addition to the PredICTor international version of Terranimo, the Swiss PredICTor group in cooperation with national Swiss authorities has created two modified versions of Terranimo: ‘Light’ and ‘Expert’. These can be accessed from www.terranimo.ch and deviates in miscellaneous ways from the general version, Terranimo International.

The European-wide WLCC maps may serve as a tool for the EU and for national authorities in land use planning and regulation. A range of maps has been created providing an overview of the effects of tyre type, inflation pressure and soil water content. The maps will be added to the abovementioned website later in 2013.

Description of activities and final results

List major objectives of the project. Describe briefly whether the objectives of the research have been achieved and outline the principal outcomes of the work and their significance to the field. (3- 6 pages).

Project objectives and planned deliverables

The overall objective of this proposal was to combine data on machinery, soil and weather with knowledge on the soil compaction process in order to predict the sustainability of any planned traffic event. More specifically, the project aimed at i) building an online decision support system regarding the sustainability of a planned traffic event in the field, and ii) creating maps of the wheel load carrying capacity (WLCC, defined as the maximum load any specific tyre at any given inflation pressure can carry without inducing permanent compaction of subsoil layers) for all European countries.

Both deliverables were provided during the project work although the automatic access to electronic databases could only be fully implemented for one of the participating countries. The following gives examples of the results obtained.

Models for soil stress and soil strength

A basic prerequisite for any evaluation of soil compaction is knowledge on the mechanisms active in the machine-soil system to be modelled. Thus, the project included thorough evaluation of modelling and calculating i) the stress distribution in the tyre-soil interface, ii) the transmission of vertical stress in the soil profile, and iii) soil strength as affected by soil type (soil textural composition) and soil matric potential. It is beyond the scope of this report to go into detail with this. In short, we developed prediction equations for the so-called FRIDA model parameters from an existing data set, using independent data for validation. FRIDA is a model describing the stress distribution in the tyre-soil interface (Keller, 2005; Schjønning et al., 2008). Some of this work has already been published internationally as part of the PredICTor project work (Schjønning et al., 2012; see PredICTor reference list in section “Exploitation and dissemination measures”), while work is still in progress for publishing the exact prediction equations used in the decision support tool. The project work also included a basic calibration of the stress transducers used in the measurement programs behind the data set mentioned above (Lamandé et al., 2013; see PredICTor reference list). Regarding the stress propagation in the soil profile, we implemented a model taking into account stress ‘concentration’ influenced by soil water regime. We expect better models to be developed in the future (hence to be implemented in the tool later), and as part of the PredICTor project, some results on this issue have been prepared for publication (Keller et al., 2013; see PredICTor reference list). Finally, the prediction equations for soil strength were developed from existing data sets on uniaxial confined compression tests. As part of the project work, we developed a new, numerical method for estimating the maximum curvature of the stress-strain relation obtained in compression tests (Lamandé et al., 2012; see PredICTor reference list). The stress at maximum curvature was interpreted as a soil strength expression (in literature often labelled precompression stress). Multiple regression analyses of a large, existing data set pointed out soil clay content and the soil matric potential as the main determinants of the ‘precompression stress’. This prediction equation formed the basis for the effects of soil type and water now implemented in Terranimo (this work will be published later). Next, we used field observations of stress-strain at a water content of field capacity (Keller et al., 2012; see PredICTor reference list) to scale the soil strength expression to field conditions.

The above is the core, scientific basis of the advice provided by the decision support system (Terranimo) as well as by the Wheel Load Carrying Capacity maps, both developed in the PredICTor project. It should be noted that two national Swiss versions of Terranimo (see later) integrates the above in a slightly different way than the common (international) Terranimo.

Deliverable 1: Online decision support system (Terranimo)

Basic features of Terranimo

Terranimo is designed with three separate components (Fig. 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.

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, Finnish and Swiss versions are run from similar .dk, .fi and .ch websites, respectively. We are currently re-arranging websites and domains. At present, the Swiss version may not be available. If so, please use http://www.soilcompaction.eu/defaultCH.aspx. 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.

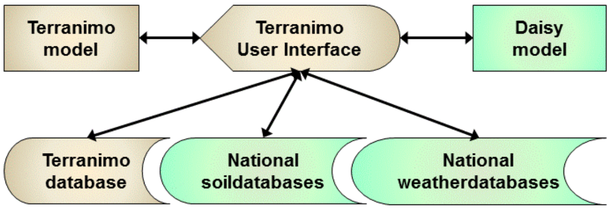

Fig. 1. Terranimo system components (model, user interface and database), the external model and country-specific databases and the interactions between them.

Input in user interface

There are two tab pages for input in the user interface: one for machinery (Fig. 2) and one for site information (Fig. 3). Two other tabs provide output from the calculations. 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 parameters are provided, which means that a direct access to the output tabs creates results for these pre-selected combinations of machinery and site characteristics. 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 default 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 (Fig. 2). 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.

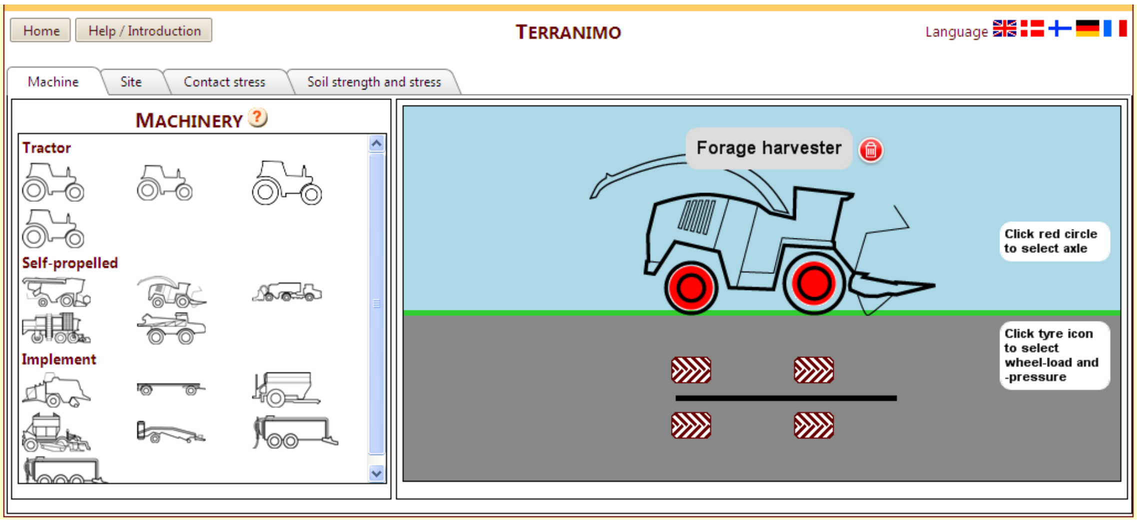

Fig. 2. Panel for selecting machinery (left), and selected machinery (right) with the option of selecting tyre type, wheel load and inflation pressure.

Basic data for site characteristics can be entered on the tab page labelled 'Site' (Fig. 3). Latitude/longitude of a location may be input for automatic access to external databases on soil and weather. The crop grown at the given location may similarly be input for the purpose of model-calculation of soil water content (see section below for these options).

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

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.

3. The option for 'Manual texture' allows the user to input soil texture for his/her own specific field in case data are available.

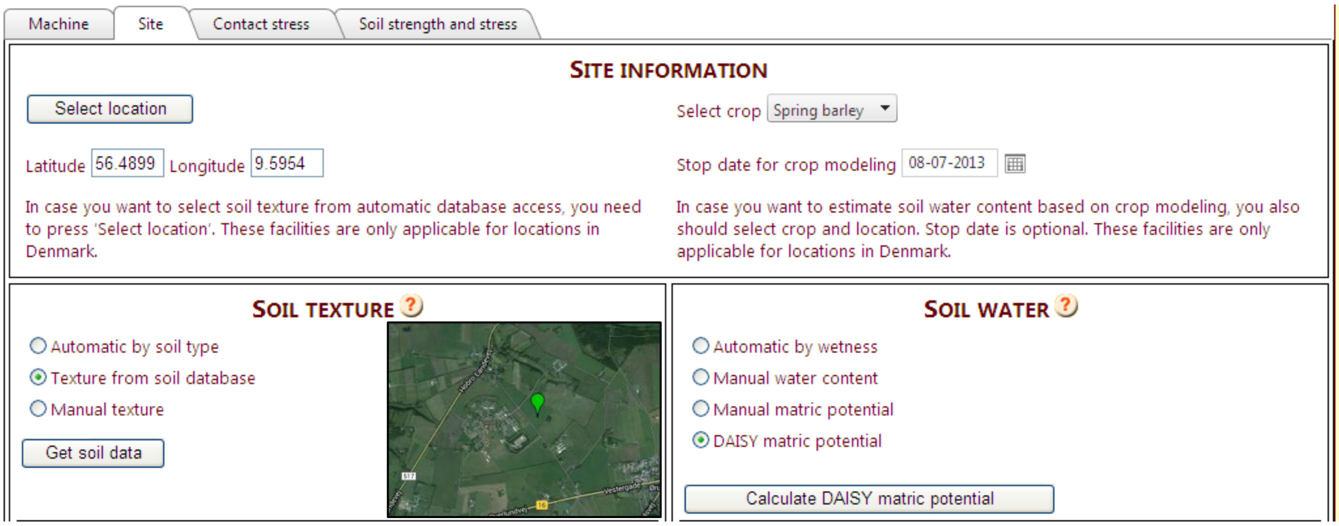

Fig. 3. Panel for describing the site to be evaluated. Soil texture (left) and soil water data (right) can be input in different ways as described in the text. Here soil texture was selected from the Danish soil data base. Insert map shows location of the specific field selected. In the present simulation, soil water was estimated by the Daisy model taking use of weather data from the closest station.

Four possibilities for obtaining soil water data are available (Fig. 3).

1. The default option is 'Automatic by wetness'. Three different water regimes are defined: 'Wet', 'Moist' and 'Dry'. These relates to water regimes approximately as 'winter situation', 'field capacity', and 'moderately dry in growing season', respectively.
2. The user may input measured water contents for the specific soil in question. Terranimo will then calculate the corresponding matric potential from soil texture.
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 the soil-plant-atmosphere-continuum model Daisy (Abrahamsen and Hansen, 2000) (see section below).

Terranimo database

The database contains tables grouped around machinery and soil. 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. A tyre is related to each wheel, and each tyre has a relation to a set of inflation pressure data in order to estimate recommended inflation pressure.

The data on soil type has one-to-many relations to both soil horizons and soil layers. Similarly, 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.

Interaction with external databases

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 (July 2013), automatic access to data bases has been implemented for Denmark. A similar facility – using an Excel data base – is functioning in a special Swiss version of Terranimo (see section "Explanation of the use of resources"). Work is in progress to establish web-service access for Switzerland and Finland, 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 identifiers 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 model (Abrahamsen and Hansen, 2000) 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 from the selected date of simulation. 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.

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 below the wheels for any of the axles on the selected machinery). Finally, soil stress is compared with soil strength as calculated for the selected soil type and water regime (Fig. 4).

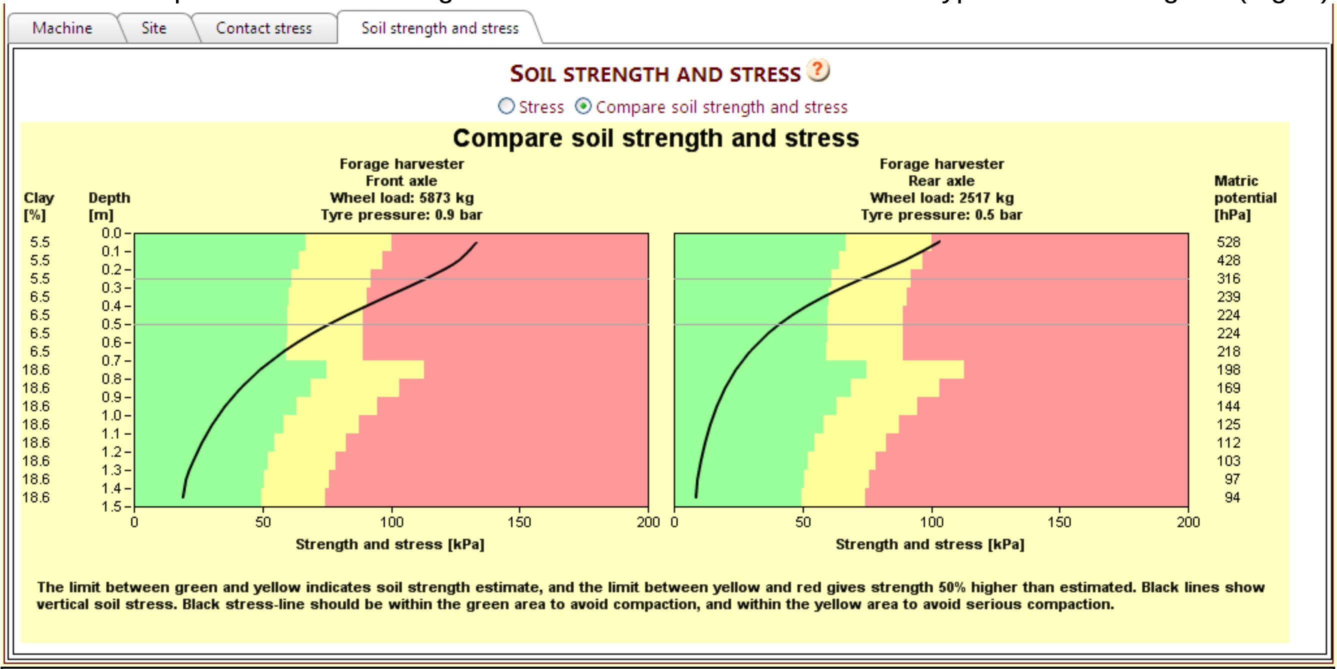

Fig. 4. Terranimo comparison of vertical stresses from machinery and soil strength as calculated from soil texture and soil water regime.

The results in Fig. 4 derive from a self-propelled forage harvester (Fig. 2) driving on a loamy sand soil close to Research Centre Foulum, Denmark (output from site characteristics selected in Fig. 3). To the right is shown the matric potential for 15 soil layers 0.1 m thick from the surface to 1.5 m as calculated by the DAISY model. To the left is shown the soil clay content of each 0.1 m soil layer. The two graphs compare stress and strength for wheels on the front and rear axles of the machine, respectively. The border between the green and yellow areas in the plots indicates the estimated mechanical strength for the soil at different depths and is therefore identical for both graphs. We note an increase in mechanical strength when going from the 0.6-0.7 to the 0.7-0.8 m layer, which is due to higher clay content. The decrease in strength with depth below that layer is – in turn – due to an increase in matric potential (less-negative values shown without minus-sign to the right in the Figure). The border between yellow and red indicates a strength level 50% higher than the actual estimate of strength. The black lines indicate the Terranimo-estimated vertical stress in the middle of the tyres below each axle. Ideally, the stress should be lower than the strength at all depths to avoid soil compaction (i.e., black line within the green area only). The risk of soil compaction increases the more stress (the black line) propagates to the right in the yellow or even red area. The 50% limit between yellow and red is arbitrary but given based on the assumption that compaction is getting really serious if stress exceeds strength that much.

For the intended traffic situation evaluated here, Terranimo predicts sustainable traffic conditions for the tyres on the rear axle, while there is a risk of compaction for soil layers down to 0.5-0.6 m for the front axle tyres, each loaded with 5873 kg. Based on this Terranimo output, the user may easily shift back to the machinery tab and modify the weight on the front tyres and/or change the tyres used. Such interactive use of Terranimo provides a good overview of which machine and soil characteristics have the highest impact on the risk of soil compaction.

Deliverable 2: Wheel Load Carrying Capacity Maps for Europe

As part of the PredICTor project, the soil analytical database connected to the EU soil map at scale 1:1000000 has been expanded so information on texture, organic matter content, pH and bulk density are available for the dominant soil types in the various mapping units building up the EU-soil map. Based on this updated soil data, we calculated the Wheel Load Carrying Capacity (WLCC) for a range of combinations of matric potentials, soil depths (depths with no deformation allowed) and tyre types / tyre inflation pressures. In this, we implemented the same models and prediction equations as used in the interactive Terranimo decision support tool.

The WLCC is dependent on tyre dimensions and the tyre inflation pressure. Fig. 5 shows an example of the maps created, here for an implement tyre frequently used for agricultural trailers. The simulation shown is for factory-recommended inflation pressure. The soil water regime relates to a matric potential of -500 hPa, which is the situation at moderate water consumption in the growing season. The present map shows the WLCC estimates for a soil that is

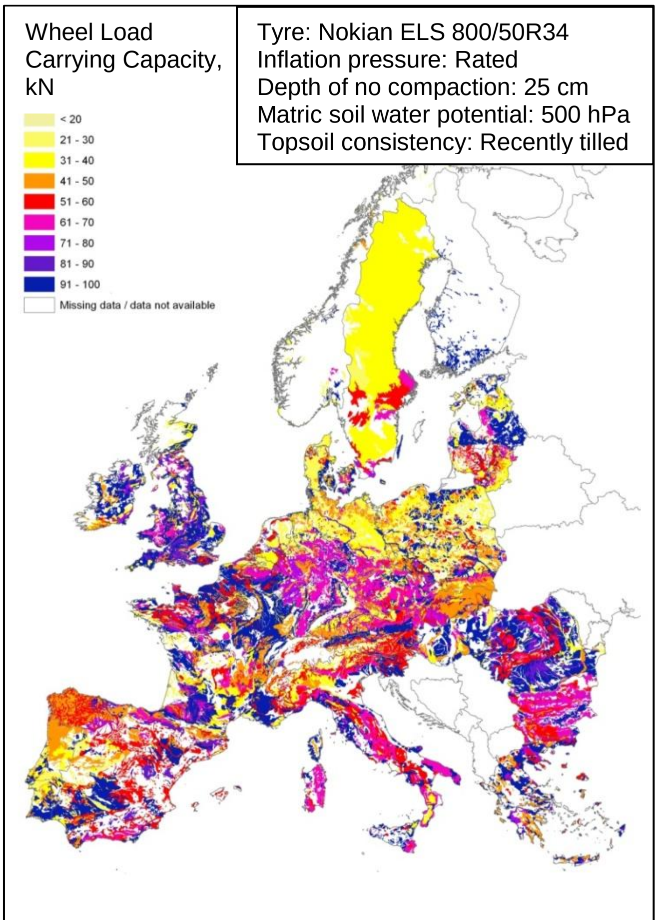

Fig. 5. Map of Wheel Load Carrying Capacity for Europe as based on updated soil data and using the models and prediction equations also active in Terranimo.

recently tilled (the topsoil consistency affects the stress in the tyre-soil interface). Finally, the WLCC shown here relates to the sustainability criterion that no compaction should be allowed for soil below 25 cm depth. It is important to note that this is a choice that is affected by an evaluation of the persistency of soil deformation created. A range of studies indicates that all subsoil layers (layers not normally tilled) have a poor resilience to compaction (e.g., Berisso et al., 2012). However, other studies anticipate that compaction of the upper subsoil layers (e.g. 25-50 cm depth) is less serious as compaction of deeper layers (e.g. Håkansson and Reeder, 1994).

The map shows high values of WLCC for soils with high clay content, while sandy soils are more prone to compaction at this water regime (e.g., see difference between the western, sandy soils of Denmark as compared to loamy soils to the east of Denmark). We note that – despite the update of the soil data base performed as part of the PredICTor project – there are still areas of Europe with missing data (white symbol). It also seems that for some countries, the data provided have a very low resolution (e.g. Northern part of Sweden).

At a matric potential of -100 hPa, the pedotransfer function used for prediction of soil strength points out nearly identical WLCC values for all soils, independent of soil texture. This means all soils have about the same WLCC (~30 kN, corresponding to ~3 tonnes) at a water content close to field capacity (data / map not shown).

A range of the maps produced will be made online available on the www.soilcompaction.eu web-site, as a parallel to the Terranimo tool. We regard the maps valuable especially for public authorities dealing with regulation and planning of land use. There is a potential, however, for producing similar maps at smaller scales (e.g. national, regional, or even field scale), which may catch the interest also of the end-user.

References (see PredICTor-produced scientific papers in the section “Exploitation and dissemination measures”)

Abrahamsen, P., Hansen, S. 2000. Daisy: An Open Soil-Crop-Atmosphere System Model. Environ. Model. Software 15, 313-330.

Berisso, F.E., Schjønning, P., Keller, T., Lamandé, M., Etana, A., de Jonge, L.W., Iversen, B.V., Arvidsson, J.,Forkman, J. 2012. Persistent effects of soil compaction on soil pore size distribution and gas transport in a loamy soil. Soil & Tillage Research 122, 42-51.

Håkansson, I., Reeder, R.C. 1994. Subsoil compaction by vehicles with high axle load – extent, persistence and crop response. Soil & Tillage Research 29, 277-304.

Keller, T. 2005. A model to predict the contact area and the distribution of vertical stress below agricultural tyres from readily-available tyre parameters. Biosyst. Eng. 92, 85-96.

Schjønning, P., Lamandé, M., Tøgersen F.A., Arvidsson, J., Keller, T., 2008. Modelling effects of tyre inflation pressure on the stress distribution near the tyre-soil interface. Biosyst. Eng. 99, 119-133.

General description of the cooperation over the duration of the project

Factual description, specifying the input of each participant. Describe the added value of doing the work in a transnational project, compared to the description in the project proposal
Work progress and achievements by work package (1-2 pages).

Project organization

The project activities were scheduled for four workpackages:

WP1: Soil mechanical models and pedotransfer functions
WP2: Preparation of national databases for interactive use by the online tool
WP3: Web-programming of the online decision support tool
WP4: Online wheel load carrying capacity maps of European soils

Per Schjønning, Aarhus University, Denmark, served as project/consortium coordinator, while Thomas Keller (Agroscope ART), and Laura Alakukku (Helsinki University) served as national coordinators for Switzerland and Finland, respectively. Work packages 1-4 were headed by Thomas Keller (Agroscope ART, Switzerland), Harri Lilja (MTT, Finland), Poul Lassen (Aarhus University, Denmark), and Henrik Breuning-Madsen (Copenhagen University, Denmark), respectively. The two consulting partners were not financially supported by ICT-AGRI. They were given the opportunity to give inputs to the project work, especially by participation in the project kick-off meeting.

Summary of project work and cooperation

A project kick-off meeting was held in Copenhagen the 22nd March 2011 with participation of all project participants except the Institute for Agri Technology and Food Innovation. Also the associated, non-funded consulting partners participated here (minutes from the meeting was provided as an appendix to the midterm report). A roadmap for the work in the project was created. The tasks in each work package were discussed and specified including the knowledge available at the meeting. The diversity in expertise and research disciplines (agricultural engineering, soil physics and soil mechanics, soil geology and geography [soil data bases]) included in the project made it clear that much of the project work had to be carried out in subgroups with the consortium coordinator linking things together. A meeting was held in Zurich, Switzerland 7-8 February 2012 for WP1-3 participants (Poul Lassen, Mathieu Lamandé and Per Schjønning, Aarhus University, Laura Alakukku, Helsinki University, Harri Lilja, MTT Agrifood Research Finland, Thomas Keller, Agroscope ART and Matthias Stettler, Bern University of Applied Sciences [former Swiss College of Agriculture]).

In **WP1** intensive email communication has formed the basis for project progress. Further, a range of informal meetings were held between Thomas Keller (WP1 leader), Mathieu Lamandé and Per Schjønning at miscellaneous occasions (especially during visits of Thomas Keller at Aarhus University, Research Centre Foulum in connection to PhD courses, PhD exams etc.). We re-visited a range of existing data on soil strength and stress propagation below wheels and identified new relations between driving variables and soil behaviour (e.g. the effect of soil clay content and soil matric potential on soil strength). Some of these new insights have been published as part of and during the project; other are still (summer 2013) being prepared for publication. Please consult section “Models for soil stress and soil strength” above for some detail of these achievements. The scientific papers produced are listed in section “Exploitation and dissemination measures”.

The initial steps in **WP2** included the protocol for automatic access from the online decision support tool to – in the first instance – the Danish soil data base. This was done during several meetings between WP3 leader Poul Lassen and Danish soil data base experts (including PredICTor participant Mogens H. Greve). Next, the implementation of the protocol to reach the Finnish and Swiss soil and weather data bases has included work in national sub-groups in Switzerland as well as Finland. Switzerland employed a commercial company to prepare the connection to the Swiss soil data base, while miscellaneous experts have been involved in the same task for Finland. It has proven difficult to get the communication to work for the Swiss and Finnish databases, while it works for Denmark. The problems relate to miscellaneous differences in protocols for communication and structures of databases. As an example, databases on soil as well as weather in Finland are built according to the Open Geospatial Consortium standards. Here, open source software has traditionally been in use for providing the services demanded by the INSPIRE-directive. Terranimo in its current version could not utilize the WFS (direct access) interface to communicate with the Finnish Soil Database 1.0 or FMI's weather data, and it was impossible to implement the web service based on Microsoft .NET technology as decided at the Kick-off meeting. Work will continue for getting the communication to work for Finland and Switzerland following the formal closure of the PredICTor project. Please also see section "Explanation of the use of resources".

The work in **WP3** has included intensive exchange of information between project participant experts in agricultural engineering and soil mechanics on one side and WP3 leader Poul Lassen on the other. Please see a range of details of the tasks involved and the results obtained in the former main section of this report ("Description of activities and final results"). Groups of test users including especially farmers, contractors, and farmers' advisers were involved in tests and evaluation of beta-versions of the Terranimo tool in Denmark as well as in Switzerland. A similar test was performed by students at Helsinki University.

The initial work in **WP4** was carried out in cooperation between WP4 leader Henrik Breuning-Madsen and Mogens H. Greve. Based on the SPADE8 database Henrik Breuning-Madsen constructed a database with information on texture, organic matter and bulk density for all dominant soil types. A meeting including the consortium coordinator was held at Research Centre Foulum in the autumn 2011. The calculation of the wheel load carrying capacity (WLCC) for all soil types in the European-wide data base was carried out by Mathieu Lamandé. Finally, maps based on these data were generated by Mogens H. Greve.

Impact statement

Please give a short description of impacts resulting from work, including synergies with transnational partners, and interdisciplinarity (1-2 pages)

The PredICTor project outcome is based on previous work in national groups in Denmark and Switzerland. This has influenced the progress made during the rather short project. We regard the products now available (the Terranimo online tool as well as the WLCC maps) as valuable for a range of users. The Terranimo decision support tool provides the opportunity to quickly test the combination of a range of different machine (tyre) characteristics with soil type, soil water regime and soil tillage effects. This has proven valuable also as inspiration to further research needs. The easy and interactive combination of all the various variables in play for the resulting risk of compaction is valuable for the researcher as well as the practical end-user. This is because the quantitative importance of all possible combinations of different drivers is difficult to imagine before putting the sub-effects in a combined model (i. effects of tyre characteristics, wheel load, inflation pressure, tillage situation, topsoil clay and water contents on the stress distribution in the tyre-soil contact area; ii. the effects of tyre-soil contact area stress distribution and the soil water content on stress propagation in the soil profile; iii. the effects of soil horizon contents of clay and water on soil strength). The WLCC maps (and actually also the Terranimo tool) may be used by public authorities in evaluation of the areas in Europe that are most vulnerable to soil compaction. Finally, Terranimo gives the end-user (farmers, contractors, farmers' advisors) the opportunity to evaluate specific traffic situations and to test alternative machinery for more sustainable farming.

As a spin-off result of the work in PredICTor, the Swiss group has succeeded to produce a decision support tool that has already been adapted and approved by the Swiss authorities for legal regulation of traffic by Swiss farmers in their fields within the context of the "Guidelines for environmental protection in agriculture" (see www.blw.ch). This work has included a focus on a user-interface that is optimized for end-users not familiar with scientific terminology and aiming more directly at the final advice. The experience that will be gathered in Switzerland may facilitate the implementation of similar, simplified tools for other countries.

The outcomes of PredICTor should be seen as prototypes for further development. First, our work with the modelling of the soil compaction process has revealed a range of further research needs to improve the predictions. This relates especially to (the methodology for) the quantification of soil strength relevant to biota-affected agricultural soil experiencing quick loads when driven over by wheels in contrast to geotechnically focused deep-horizon soil that is long-term loaded under buildings. Also, more studies are urgently needed to point out the soil mechanical characteristic of highest relevance to (reductions in) soil functions. The prediction equations for soil mechanical strength need to be confirmed especially for heavy clay soils (e.g. in Finland). Most probably, future work will also improve our modelling of stress propagation in the soil profile. Finally, work is in progress to refine the prediction equations for the stress distribution in the tyre-soil interface as the presently implemented equations over-predicts the contact area for very big tyres at high wheel loads.

The direct access to data bases (soil and weather) is a strong facility in Terranimo as it allows the user an easy prediction for soils and crop/weather conditions of immediate interest (see Fig. 4 in the former section of this report). Here, ICT proves its potential in optimizing knowledge transfer. However, more work is needed to create standards and protocols to easily create contact to data bases in interested countries that may have varying formats for their data. The Danish group will continue this work after the termination of the PredICTor project as financed by other projects (see below).

The DAISY-model prediction of soil water matric potential at different depths for different soil types and for a given crop at a given date is another facility that enhances the usefulness of Terranimo. In case the weather data bases include a forecast of the data needed, prognosis for compaction risk may easily be implemented in Terranimo. We expect all needed data to be forecasted by the Danish Meteorological Institute in the near future, which will then enable a seven day forecast that may be very useful e.g. in planning harvest operations.

Country-specific versions of Terranimo can easily be made available to new, interested countries. This will imply specific machinery and default soil types. In case any new country might not be covered by the present five languages available, a version with the specific language can quite easily be created by translation of all Terranimo labels and texts. The new language terms will appear automatically when the translated resource file has been implemented in the system. A specific agreement has already been made with a Norwegian project, meaning that a Norwegian version of Terranimo will soon be available (probably during 2014).

The PredICTor group has contact to other research groups interested in miscellaneous developments and improvements of the Terranimo tool (e.g. the Rai-SoilComp project funded through the ERA-NET Snowman). It is yet to be decided how modules with new facilities may best be implemented in Terranimo.

The PredICTor group has had contact to the EU Joint Research Centre about the option of preparing for a display of the Terranimo online decision support tool as well as the WLCC maps on JRC servers. This potential has to be further discussed but includes the potential of letting the PredICTor outcome facilitate e.g. the implementation of the planned EU Soil Framework Directive.

Terranimo will specifically be further developed during a new EU project ‘RECARE’ (2013-2018) coordinated by Coen Ritsema from Wageningen University. This project addresses all eight threats to a sustained soil quality that were addressed by the EU Soil Thematic Strategy. Aarhus University will chair the work on soil compaction, including the further development of Terranimo. The Swiss partners in PredICTor also are partners in the upcoming RECARE project.

Exploitation and dissemination measures

Patents, new cooperations, new products (1-2 pages).

Dissemination of results

The decision support system (Terranimo) is available at the web (www.soilcompaction.eu; tab 'Terranimo'), while the second main deliverable – the Wheel Load Carrying Capacity maps – is yet to be released but will soon appear at the same web site (tab 'Wheel Load Carrying Capacity maps').

The work and results from the PredICTor project have been presented for the public in several ways. An interview with WP1 leader Thomas Keller and consortium coordinator Per Schjønning was presented in the international journal 'Research Innovation' (http://extranet.djf.agrsci.dk/sites/poseidon-nordic/offentligt/Documents/Publications/ResearchMedia-brochure.pdf). Project results were presented at miscellaneous national and international conferences and seminars (e.g. the NJF seminar 'Soil compaction – effects on soil functions and strategies for prevention', March 6-8, 2012 in Helsinki: http://www.njf.nu/filebank/files/20120620$212221$fil$hvMDCSgYtPqj0z2OK8tK.pdf), see presentation titles in the list below.

The Swiss versions of Terranimo are already in use for regulation of agricultural traffic in Switzerland and can be accessed from www.terranimo.ch.

Scientific papers deriving from PredICTor and produced during the project period

Keller, T., Arvidsson, J., Schjønning, P., Lamandé, M., Stettler, M. & Weisskopf, P. 2012. In situ subsoil stress-strain behavior in relation to soil precompression stress. Soil Science 177, 490-497.

Keller, T., Lamandé, M., Arvidsson, J., Berli, M., Ruiz, S., Schjønning, P. & Selvadurai, A.P.S. 2013. Transmission of vertical stress under agricultural tyres: Comparing measurements with simulations. Soil & Tillage Research (submitted).

Lamandé, M., Keller, T., Berisso, F.E., Stettler, M. & Schjønning, P. 2013. Accuracy of soil stress measurements: calibration of four transducers in the field. Soil & Tillage Research (submitted).

Schjønning, P., Lamandé, M., Keller, T., Pedersen, J. & Stettler, M. 2012. Rules of thumb for minimizing subsoil compaction. Soil Use and Management 28, 378-393.

Conference presentations

Alakukku, L. & Lilja, H. 2012. PredICTor –hankkeessa työkalu pohjamaan tiivistymisriskin ennustamiseen. Julkaisussa: Maataloustieteen Päivät 2012 [verkkojulkaisu]. Suomen Maataloustieteellisen Seuran julkaisuja no 28. Toim. Nina Schulman ja Heini Kauppinen. Viitattu [21.1.2012]. Julkaistu 15.1.2012. Saatavilla Internetissä: www.smts.fi (kyseisen artikkelin nimi). ISBN 978-951-9041-56-8. Abstrakti (In Finnish).

Keller T., Arvidsson J., Schjønning P. & Weisskopf P. 2012. Soil compaction: effects on soil functions and strategies for prevention. X Latin American and Caribbean Congress of Agricultural Engineering (CLIA) and XLI Brazilian Congress of Agricultural Engineering (CONBEA), 15-19 July 2012, Londrina, Brazil.

Lamandé, M., Keller, T., Labouriau, R., Schjønning, P., 2012. Numerical method for determination of point of maximum curvature on soil compression curves from uniaxial confined compression tests. In: Proceedings of the 19th 337 International Conference of ISTRO, Montevideo, Uruguay, Paper no. 395.

Lassen, P., Jørgensen, M.S., Stettler, M., Lamandé, M., Keller, T., Lilja, H., Alakukku, L., Pedersen, J., Hansen, T.K., Nielsen, J.A. & Schjønning, P. 2012. Terranimo – a web-based tool for evaluating soil compaction: Model design and user interface. In: Alakukku, L., Kymäläinen, H-R. and Pienmunne, E. (Eds.) Soil compaction – Effects on soil functions and strategies for prevention. Proceedings, NJF-seminar 448, Helsinki, Finland, 6-8 March 2012. NJF Report 8(1), ISSN 1653-2015, pp 83-86.

Lassen, P., Lamandé, M., Stettler, M., Keller, T., Jørgensen, M.S., Lilja, H., Alakukku, L., Pedersen, J. & Schjønning, P. 2013. Terranimo – A soil compaction model with internationally compatible input options. EFITA-WCCA-CIGR Conference "Sustainable Agriculture through ICT Innovation", Turin, Italy, 24-27 June 2013.

Schjønning P., T. Keller, M. Lamandé, M. Stettler, P. Lassen, L. Alakukku, T. Børresen, N. Jarvis, P. Dörsch, J. Arvidsson, A. Simojoki, B.V. Iversen, A. Etana, K. Regina, M. Larsbo, F.E. Berisso, M.S. Jørgensen, H. Silvennoinen, M. Mossadeghi, H. Lilja, H. Breuning-Madsen, M.H. Greve, J.J.H. van den Akker, J. Rücknagel, J.A.Nielsen & J. Pedersen. 2012. Risk assessment and effects of soil compaction: Research chains at work. In: Alakukku, L., Kymäläinen, H-R. and Pienmunne, E. (Eds.) Soil compaction – Effects on soil functions and strategies for prevention. Proceedings, NJF-seminar 448, Helsinki, Finland, 6-8 March 2012. NJF Report 8(1), ISSN 1653-2015, pp 13-16.

Stettler, M., Keller, T., Schjønning, P., Lamandé, M., Lassen, P., Pedersen, J. & Weisskopf, P. 2012. Terranimo – a web-based tool for evaluating soil compaction: Machinery-induced stresses versus soil strength. In: Alakukku, L., Kymäläinen, H-R. and Pienmunne, E. (Eds.) Soil compaction – Effects on soil functions and strategies for prevention. Proceedings, NJF-seminar 448, Helsinki, Finland, 6-8 March 2012. NJF Report 8(1), ISSN 1653-2015, pp 87-90.

Popular-science articles and oral presentations for end-users

Anonym. 2013. Uusi menetelmä maan tiivistymiseen. Vako 1/2013: 5 (in Finnish). Interview with L. Alakukku.

Keller, T., 2013. Physikalischer Bodenschutz: Vorsorge gegen Bodenverdichtungen - Beratungsempfehlungen für landwirtschaftliche Nutzungen. Oral presentation (in German), Bodenseminar 2013 "Beurteilung der Bodenqualität unterschiedlich bewirtschafteter Böden", LFZ Raumberg-Gumpenstein, Irdning, Austria, 4 June 2013.

Schjønning, P. 2013. Jord og maskiner – påvirkning af frugtbarhed (http://www.nordicbeet.nu/public_site/webroot/cache/media/file/Jord_og_maskiner_sax130205_PS.pdf). Oral presentation (in Danish), Winter meeting in Nordic Beet Research, February 5 2013.

Schjønning, P., Lamandé, M. & Nielsen, J.A. 2012. Bæredygtig trafik i marken. Økologisk Planteavlsberetning 2012, Økologisk Rådgivning Gefion, pp. 3-6.

Schjønning, P., Lamandé, M., Nielsen, J.A., Høy, J.J., Berisso, F.E., Wildenschild, D., Etana, A., Lassen, P., de Jonge, L.W., Keller, T. & Arvidsson, J. 2011. Jordpakning – hvordan pakkes jorden, hvad er effekten, og hvordan forebygger vi? Oral presentation (in Danish), 'Plantekongressen', Herning, Danmark, January 11-13 2011.

Schjønning, P., Lamandé, M., Berisso, F.E., Etana, A., Wildenschild, D., Lassen, P., de Jonge, L.W., Keller, T. & Arvidsson, J. 2011. Jordpakning - processer, effekter og forebyggelse. Oral presentation (in Danish), 'Bioforsk-konferansen', Sarpsborg, Norge, February 9 2011.

Stettler M. 2011. Reifendruck und Bodendruck. Live wheeling experiments and oral presentation (in German), "Praxistag" Witzwil, Switzerland, August 29 2011.

Stettler M. 2011. Bereifung und Bodendruck. Live wheeling experiments and oral presentation (in German), "Ammoniak-Tag", Zollikofen, Switzerland, May 20 2011.

Stettler M. 2011. Bodendruck und Bodenverdichtung. Oral presentation (in German), "Weiterbildungsmodul Lohnarbeiten", Zollikofen, January 14 2011.

Stettler M, 2012. Der zerdrückte Raum: Bodenverdichtung. Oral presentation in German. Kolloquium des Amtes für Landschaft und Natur des Kantons Zürich, 13. Dezember 2012, Zürich.

Stettler M, 2012. Interview Reifendruckregelanlagen. Schweizer Landtechnik, Oktober 2012, 21.

Stettler M, 2012. Vollzugshilfe Bodenverdichtung & Computermodell Terranimo. Oral presentation. Tagung BDU – Fachgruppe Erosion & Bodenfruchtbarkeit, 30. Mai 2012, Rütti, Zollikofen.

Stettler M und Berger S, 2012. Bodendruck unter Güllefässern. Live wheeling experiments and oral presentation in German. Strickhof Boden-Tag, 29. August 2012, Strickhof in Lindau.

Stettler M & Schmid B, 2012. Erstaunlich hohe Drücke. Die Grüne, Nr. 18/2012, 20-25.

Stettler M & Zihlmann U, 2012. Bodenstruktur und Bodentragfähigkeit. Oral presentation. Flurbegehung von Swiss No-Till, 12. Juni 2012, Betrieb Franz und Marianne Rösli, Wartensee, Sempach-Station.

Stettler, M. & Keller, T. 2011. Terranimo – EDV senkt Bodendruck. Die Grüne, Servicebeilage Lohnunternehmer, Nr 10 vom 19. Mai 2011, pp. 25-27.

Stettler, M. & Keller, T. 2012. Verdichtungsvorbeugung. Oral presentation „2. Berner Bodentag", Zollikofen, Switzerland, 18 October 2012.

Stettler M, Berger S & Meyer G, 2012. Kleine Radlasten und grosse Reifen, das wärs. Die Grüne, Nr. 22/2012, 24-27.

Weisskopf P., Keller T., Obeholzer H.-R. & Zihlmann U. 2012. Böden: Verdichtungsrisiko erkennen und reduzieren. Ein neues Hilfsmittel kommt. Schweizer Bauer vom 2. Juni 2012, Jahrgang 166, Nr. 44, p. 19.

Explanation of the use of resources (final financial report)

List any deviations in participant's use of resources pertinent to the project as a whole, describe corrective actions adopted for any deviations (1-2 pages).

The work within the Danish group did not deviate much from the planned. We needed to involve additional experts in web-service communication and soil data base structure. Also an expert in the DAISY model was attached to the group at Aarhus University to successfully implement the DAISY model. However, these changes did not affect the overall budget or the planned outcome of the work.

The work in Finland included development of the soil database 1:250.000 to better fulfil the requirements of Terranimo. After the development work, the database will get a new version number 1.1. and will include: 1) Update of soil classification WRB1998 to WRB 2007; 2) Update of the soil physical database with coordinates so that it can be implemented to the Finnish soil data base 1:250.000 version 1.1.; 3) Fix bugs found in soil database version 1, (there was an error in pedotransfer function in bulk density calculation); 4) Add new estimations of physical properties of deeper horizons of clay soils (actually pseudogley and Stagnosols with WRB 2007 classification); 5) Update the user guide of soil database 1.0 to version 1.1 (the guide is published only in electronic format); 6) Publish the version 1.1 as POSTGis database to provide faster communication to external clients like Terranimo.

The Finnish group included national experts in the work with the communication problems (Jukka Rahkonen from TIKE; Andrea Aime from Geoserver steering committee; Roope Tervo from FMI's beta team).

In addition to the work on the common Terranimo tool, the Swiss group started developing a specific national (Swiss) web tool based on the basic model developed in PredICTor. For that purpose – at the request of the Swiss group – the programming code was transferred from the server at Aarhus University to servers at the commercial company afca in Switzerland. The Swiss tool is aimed for use by Swiss farmers, contractors and the Swiss authorities (e.g. cantonal soil protection agencies) in legal regulation of farmer's traffic in agricultural field, and the official tool of the "Guidelines for environmental protection in agriculture" that were jointly prepared by the Federal Office for Agirculture (FOAG) and the Federal Office for the Environment (FOEN). The Swiss tool deviates in miscellaneous ways from the common Terranimo tool,- also with respect to outputs and advice for the user. The "Swiss Terranimo" (www.terranimo.ch) will be maintained and up-dated in future by the Swiss PredICTor partners in collaboration with afca and FOAG.

The Finnish group has extended the national Finnish part of the PredICTor project to the end of 2013.

It is the experience of the project coordinator (Per Schjønning) that the Era-net concept of project funding by national funding bodies rather than one EU funding body makes the coordination of project work problematic.