A Mobile Mapping Technology Application for Smart Soil Sampling (Triple-S) on Ontario Farmland

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Abstract:

On-farm generated, geospatially-referenced field cropping system datasets have become valuable information assets for Ontario farm management. These precision agricultural databases grow with each annual addition and provide valuable information for crop planning, monitoring and traceability. Sound stewardship practices require crop plans that ensure crops have optimal nutrients and build long-term soil health. A key element to developing optimal crop plans which include fertilizer recommendations, is the analysis of soil nutrients from collected field samples. Sampling strategies to assess soil nutrient resources have for many years utilized various forms of stratified random sampling. With the advent of precision field data sets including yield maps, airborne imagery and detailed elevation data, sampling strategies can be customized to characterize the physiographic zones

This project focused on development and testing of field record management technology targeted for use on mobile devices. It combined the development of a core mobile app for comprehensive field record keeping and an extension standalone module to augment the soil sample records with a “Smart Soil Sampling” (Triple-S) mobile mapping application. The project had several challenging technology design goals which included developing a code framework that would enable the application to be deployed for Android and iOS devices and could be easily extended.

The FarmHand™ app is the core application and will be of interest to farmers and agri-businesses who looking for a mobile solution for tracking crop level operations. It has rich content that is focused on Ontario operations which includes detailed pre-populated lists for activities such as products applications, scouting records and manure credit calculations. The interface uses a responsive design that will adapt to different device sizes and take advantage of devices features such as cameras and GPS capabilities.

The Triple-S app leverages results from all available on-farm generated crop performance, soil landscape feature and soil property dataset investments to facilitate nutrient application decision-making. Farmers and agri-business professionals will be able to use this Triple-S app to guide soil sampling site location selection. It provides for targeted field inquiries of crop performance areas with different soil landscape and property characteristics. Decisions stemming from this approach will lead to enhanced nutrient use efficiency on the province’s cropland with commensurate economic return opportunities and environmental benefits.
Project Description:

Precision agricultural data collection and information management have evolved rapidly over the past decade spurred along by advancements in GPS-enabled hardware. On-farm generated, geospatially-referenced field cropping system datasets have now become very valuable and detailed information assets that grow annually to aid in the management of Ontario farms. Field record keeping combines operational data on agronomic activities, crop observations and precision agriculture. These combined datasets provide a valuable resource for providing economic and environment benefits to the farmer and the province and have yet to be fully explored. While many growers recognize that better crop data management has many benefits they face many challenges in how to collect, manage and analyse these datasets. These combined data resources have great potential for application to soil nutrient resource management for both economic return to the farmer and environmental benefits through reduced risk of water quality impairments.

This decade will see continued development and refinements of mobile technology platforms with GIS/GPS capabilities that will be used for in-field data collection and mapping. This pilot project has developed “Made in Ontario” applications that provide agricultural practitioners with a field record keeping environment and a guidance tool with which to make better decisions about farm operations and where to soil sample. Each of the tools further the ability to collect detailed agronomic data that can benefit decisions that affect both economic and environmental factors. Data technology solutions such as the ones developed in this project make it easier for growers to collect field data which should help growers collect complete and detailed data at the crop level and improve data quality. With comprehensive and good quality data in hand, agronomic practitioners are better able to make decisions that impact soil health and their role as environmental stewards.

This project developed an agriculture data management applications for mobile devices that aid in the collection and management of field-level records. The applications consists of a core mobile app for comprehensive field record keeping and an extension standalone module to augment the soil sample records with mobile mapping application that aids in the development of soil sampling zones (Smart Soil Sampling). FarmHand™ is the field record keeping component and offers a comprehensive set of activity dialogs that have been designed to meet the requirements of Ontario field crop growers. One of its features is the ability to map soil sample locations by crop year. The Triple-S (Smart Soil Sampling) application augments this capability by aiding in the development of management zones that will guide the selection of sample locations within the field.

The applications through this project contribute directly to efforts such as the 4R Nutrient Stewardship approach developed by the International Plant Nutrition Institute to develop fertilizer BMPs. This approach considers economic, social and environmental factors in developing sustainable agriculture systems.¹

¹ http://www.ipni.net/4R
The 4Rs of nutrient stewardship are:

- using the **Right Source** of fertilizer
- at the **Right Rate**
- at the **Right Time** and
- in the **Right Place**.

The 4Rs of Nutrient Stewardship provides a science-based framework for plant nutrition management. While the concept of 4Rs is simple, the implementation is knowledge intensive and site specific. Developing crop systems and management plans that are based upon scientific knowledge utilize a systems approach will benefit growers and the environment and result in:

1. Increase crop production & improve profitability
2. Minimize nutrient loss & maintain soil fertility
3. Ensure sustainable agriculture for generations to come

The **FarmHand™** mobile application assists practitioners collect operational data that can be utilized to develop site-specific 4R BMPs. It provides a framework for easily capturing nutrient inputs from manure and fertilizer sources and crop history including product application, planting details, scouting observations and harvest records. One of the 4R requirements is to better understand variation of soils within the field and how their characteristics relate to water utilization and the nutrient balance, particularly for N and P. The **Triple-S** (Smart Soil Sampling) mobile application assists practitioners in this regard by helping to decide where to collect samples that accurately represent their management zones. **FarmHand™** also allows them to collect detailed anecdotal and photographic records that will aid with differentiating management zones and developing management strategies that fit within the 4Rs of Nutrient Stewardship concept.

**Triple-S Rationale**

Geospatial soil nutrient resource characterization drives field management decisions at the within-field scale for fertilizer application in precision cropping systems. Common practice has been to grid sample farm fields for soil nutrient characterization. Recommendations for the density of this annual sample collection activity can vary widely between agri-business professionals. Additionally, this critical field information gathering practice treats each of these annual grid sampling campaigns independently of previously developed field knowledge.

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The “Triple-S” approach harnesses the accumulated field knowledge gained by all previous investments in on-farm generated crop performance, soil landscape and soil property information development. This app directs soil sampling activities to examine specific within-field nutrient management situations. Farmers and agri-business professionals will use this “Triple-S” app to investigate field scenarios that represent combinations of different crop performance results (examples: always above average, average, always below average) in different soil landscape settings (examples: upland depressions, upland hilltops, side slopes, lowland basins) with particular soil properties (examples: fine textures (mostly clay), coarse textures (mostly sand), high organic matter, low organic matter, high pH, low pH, etc.). This “Triple-S” app approach, therefore, provides for nutrient deployment planning and applications as would happen with a traditional grid sampling approach – but having directly examined targeted field locations representing scenarios of interest. It reflects science-based nutrient stewardship (the 4R, 6R or 7R approaches – right rate, right place, etc.) and will directly contribute to increased nutrient use efficiency within fields. Overall, this will provide benefits to both farm profitability and local water quality by stemming nutrient losses through this informed soil nutrient resource assessment and management.
Methodology

The applications were developed by FieldTRAKS Solutions Inc. using original code algorithms. At the outset of the project the development team did an assessment of current technology and prepared a set of both technology and application goals. The application goals identified the functional requirements of each of the applications and such things as how the application would be utilized by end-users and desirable application interface behaviours. The technology goals considered the application requirements and identified potential solutions. One of the key goals of the project was ensure the final applications will work on both Android and iOS tablets.

At the outset of the project it was identified that the application(s) would have the following features:

- Record and visualize the boundaries for Fields and Crop Zones in a map window. Fields will be defined as areas that have a physical bounding area that is generally permanent. Crops may be one or more planted areas within a field and will be created each crop year.

- Field and Crop Zones boundaries may be imported from either a SHP or KML file. A goal was to develop an import utility to download selected OMAF/MRA Ontario AgRI field polygons from a cloud server. The feasibility of implementing this feature was examined and deemed feasible but not implemented in the initial release.

- Users would be able to import and display thematic map layers for each field. These will include: Management Zone Map (1), Elevation/Topo Map (1), Yield Maps (multiple), NDVI images (multiple). Supported formats will include .SHP and .KML for vector data and .GRD and .JPG/.JPW for raster. All imported data would be in Lat/Long geographic coordinates (no projection conversions would be provided).

- Users would be able to control which thematic layer is visible and set the transparency for that layer. A second layer can be added for comparison. If a 2nd layer is added, the user will have the ability to control the transparency of that layer and have a horizontal/vertical slider which will hide/reveal the layer beneath.

- Layer controls would allow Users to alter the graphic display of fields/crops in the map window (e.g., colour by crop type, display field name, acres, etc).

- Map window would have measurement tools for calculating areas and lengths.

- Smart Soil Sampling (Triple–S) would allow the User to capture one or more photos to be tied to the soil sample location. A detailed soil description dialog would be developed with OMAF/MRA Soil Scientists to record soil characteristics that could be utilized in development of fertility plans. Users would be able to import and link PDF & JPG files to soil sample locations (e.g., PDF lab reports, digital photos, etc.).

- The FieldTRAKS Large Acre Grower User Profile would be used as the template for creating a generic field level record keeping database.
Following the completion of the initial assessment of application and technology goals, concurrent work began on:

1. Development of a prototype concept application and research/testing Javascript UIs using Model-View-View Model patterns and jQuery frameworks to test the proposed application design and deployment to mobile devices.

2. Design of the FarmHand™ data model definition which describes the database content such as the object relationship, activity definitions and the data properties of all objects and activities.

3. Research and testing of image analysis algorithms to support the image overlay processes required for Triple-S. The process developed enables a full-spectrum jpg image to be re-classified into a user-selected number of classes.

4. Storyboard conceptual application interface illustrations for the FarmHand™ app. This process involved using a whiteboard to schematically illustrate each page of the application and document the application behaviours. Figure 1 below illustrates examples from some of the dozens of whiteboards that were generated. These conceptual illustrations were then used to design & code the activity dialogs and screen layouts.

**FIGURE 1. DESIGN PHASE - FARMHAND USER INTERFACE**
The development team has created their own Application Development Tool (ADT) which generates code templates from database definitions. The ADT uses a web browser interface to connect with our cloud server which hosts a MySQL database. Through the web interface, the hierarchy of database objects are defined along with any activities associated with each object. For example, Figure 2 below illustrates the parent-child relationship between Field and Crop and that at the Field level, users can record data pertaining to Soil Samples, Fertilizer, Manure applications and Tillage activities.

![Diagram](image)

**FIGURE 2. DATA MODEL PROFILE BUILDER - OBJECT DEFINITIONS**

In this data model, a field can have many crops and each of these crops can have multiple records describing Scouting, Planting, Product Application and Harvest events.

Each object and activity can have any number of data properties or attributes that describe them. Figure 3 below illustrates the data properties that are attached to the Scouting activity. It also illustrates that a Scouting activity has multiple “sub” or “child” activities. In this case, a Scouting activity is the parent activity of other activities called Insects, Weeds, Diseases, Nutrients, Damages and Moisture.

Each one of these data properties is described in terms of its datatype (e.g., number, text, GIS, etc.), whether it has a list, whether it can have null values (i.e., the User can leave it blank), and its format or default values.
Once the data model has been created the ADT generates the code templates in different data structures that we use to build the application. These include SQL to build the database, HTML code that is used to build dialog screens, Javascript that programs data behaviours among others.

To meet the technology goals of this project, the components of the ADT were significantly extended to include new features including the addition of databindings and tags to support JQuery and Knockout frameworks. These are Javascript libraries that facilitate the development of cross-platform mobile applications.
Results

FarmHand™ Mobile Application

FarmHand™ provides Ontario row crop growers and Agri-businesses with a mobile crop management solution tailored for Ontario field crop growers that provides environmental stewardship benefits and improves their net profitability. It provides activity dialogs that are easy to use and pre-populated with all of the items commonly used in Ontario for activities such as product applications, scouting observations and nutrient management.

It is available for Android and iOS devices. Although it will work on devices of all sizes, it is best viewed on tablets where the larger screen sizes are better for viewing map data.

In an effort to deliver a clean and easy to navigate interface, the design team implemented features such as:

- A dashboard that provides information tiles that display
  - recent activity records (that can be selected for editing)
  - upcoming scheduled tasks (that can be selected for editing)
  - RSS News & Weather feeds
- Collapsible navigation panel on the left side that contains quick page links to the field display, map window, activity dialogs and other main sections.
- Collapsible right panel that displays statistical/summary data, crop year selection and action buttons for adding content.
- Pre-populated dependent lists. Many of the activity records utilize drop-down lists to make data entry fast and accurate. Where there are dependencies, the lists are automatically filtered by the selected content. For example, the scouting activities are filtered by the crop type selected when the crop is created. If it is a corn crop, the growth stages, disease lists and insect lists are filtered to those that relate to corn. In some cases these dependencies cascade for several levels (e.g., crop type > disease type > disease name). The database content for list items includes over 2000 entries include weeds, insects, diseases and application products used in Ontario.

The data model includes the following field and crop level activities:

**Field Level**
- Manure Records (OMAFRA Pub 811 Method)
- Fertilizer Records (Standard Products & Blends)
- Soil Sample (Conventional & Smart Soil Sampling/Mgt Zones)
- Tillage

**Crop Level**
- Planting
- Product Applications
- Scouting (Weeds, Insects, Diseases, Nutrients, Damages, Moisture)
- Harvest
FarmHand™ is currently a standalone product that uses local data storage and will initially be offered at no charge to Ontario growers. It has not yet been determined whether there will be fees for future versions. As illustrated in the following table, the business plan is to offer Cloud and Enterprise versions on a fee basis.

Business Plan Concept

<table>
<thead>
<tr>
<th></th>
<th>Standalone</th>
<th>Cloud</th>
<th>Enterprise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Storage</td>
<td>Local database only</td>
<td>Local &amp; Web hosted</td>
<td>Local &amp; Web hosted on dedicated servers</td>
</tr>
<tr>
<td>Multiple Growers/Farms</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes – including tiered Users</td>
</tr>
<tr>
<td>Limits on the number of Fields/Crops</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Data Privacy</td>
<td>n/a</td>
<td>Owned by Client</td>
<td>Owned by Client</td>
</tr>
<tr>
<td>Traceability Reports</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Shared Users</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Data Backup Service</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Crop Dependent Dialog Lists</td>
<td>Yes</td>
<td>Yes</td>
<td>Customized</td>
</tr>
<tr>
<td>Supports Multiple Crop Years</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>User Profile/Activity Dialogs</td>
<td>See Below</td>
<td>See Below</td>
<td>Customized</td>
</tr>
<tr>
<td>Interface with Other Applications</td>
<td>XLS Export</td>
<td>XLS Export</td>
<td>Web Services / XML</td>
</tr>
<tr>
<td>Target Devices</td>
<td>Tablets</td>
<td>Tablets &amp; Browsers</td>
<td>Tablets &amp; Browsers</td>
</tr>
<tr>
<td>OS</td>
<td>Android &amp; iOS</td>
<td>Android, iOS &amp; Windows</td>
<td>Android, iOS &amp; Windows</td>
</tr>
<tr>
<td>COST</td>
<td>FREE</td>
<td>Annual Subscription ($ tbd)</td>
<td>Service Level Agreement</td>
</tr>
</tbody>
</table>

The business plan to offer a subscription based service where Users would have the option of having their data stored in a private cloud database where they could set up sharing with other Users. This version should be of interest to agriculture service providers who work with multiple farms and growers who would like to share selected field level data.

For all versions, the User Agreement states that the data is owned by the User and will not be shared without the Users prior agreement.

At the time of this report, the application was still under development so the screen icons and layouts displayed on the following pages will be different from the published application.
Figure 5 illustrates how the app allows Users to add 1 or more farms. The current version uses local storage so all farm & crop data is stored only on the device the application is installed on. The local database can be exported so any system entries can be imported into other software that supports XML or CSV data structures.

Figure 6. FARMHAND DASHBOARD AND SUMMARY DATA/CROP YEAR PANEL
Figure 6 illustrates the Data Summary/Crop Year panel that displays summary statistics for the selected crop year and allows the User to switch between crop years. Fields are treated as permanent objects of the farm. Future enhancements will allow the User to achieve fields between years. Crops are the areas of the field planted in a given crop year. In most instances this will be the entire geographic area of the field in which case the field boundary is copied and becomes the crop boundary. The User has the option of drawing their own crop boundary which is useful if the field is split into 2 or more crops in a given crop year.

Figure 7 illustrates the collapsible navigation panel that contains the links to the main pages of each section. The navigation pane is always accessible by touching the top-left corner of the application.
Figure 8 illustrates the list view of the Field page. Here the user can switch between list, tile and detail views of the fields. Touching a field name selects it as the active item. Switching back to the navigation view and going to either the Activities window or the Map window will keep the selected field active as illustrated below in Figure 8.

If crops have been added to the field, the crop type along with the planted acres (determined by the GIS boundary) will be displayed. If there are multiple crops in a field, each crop will be listed along with the acres.
Figure 9 illustrates the Activity page where the user selects and launches activity dialogs for record inputs.

The activities at the field level are to record a: Soil Sample, Fertilizer Application, Manure Application or Tillage. Each of these buttons will launch the affiliated dialog into the full screen where the data entries are made. Once completed, the user is returned to the Activities view where they may select another activity or change field selections. Using the top menu selection for “Active Field”, the selected field may be changed from whatever was selected in the Field view.

If there is more than one crop associated with the field, each crop will be listed and will display the acres planted. Below each crop are the buttons that launch each of the activities associated with crops; Scouting, Planting, Product Application and Harvest.
### Scouting

<table>
<thead>
<tr>
<th>Date</th>
<th>02/11/2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crop</td>
<td>Barley</td>
</tr>
<tr>
<td>Growth Stage</td>
<td>Pre-Emergence</td>
</tr>
<tr>
<td>Plant Population</td>
<td>23</td>
</tr>
<tr>
<td>Population Unit</td>
<td>seeds/ft</td>
</tr>
<tr>
<td>Soil Condition</td>
<td>Normal</td>
</tr>
<tr>
<td>Scout Name</td>
<td>George Jones</td>
</tr>
<tr>
<td>Photo</td>
<td><img src="image_url" alt="Image" /></td>
</tr>
</tbody>
</table>

#### Add Scouting Observations

<table>
<thead>
<tr>
<th>Type</th>
<th>Observation</th>
<th>Severity Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insects</td>
<td>10</td>
<td>40</td>
</tr>
<tr>
<td>Insects</td>
<td>70</td>
<td>420</td>
</tr>
<tr>
<td>Weeds</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Diseases</td>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>

*FIGURE 10 - FARMHAND - SCOUTING DIALOG*
**Triple-S Mobile Application - Features**

The **Smart Soil Sampling** (Triple-S) mobile application will help Ontario farmers and crop consultants build knowledge about the variations of soil characteristics within a field through providing data collection tools that will aid them in the selection of soil sample locations and to record textual and photographic pedology data. The current recommended methodologies for soil sample site selection are to either perform grid based sampling or random samples within each 2.5 acre grid. With the growing base of precision agriculture data there is evidence that crop response varies within a field and these variations can be attributed to differences in topography, drainage, soil texture and other physical and biologic factors. Given that much the variation in crop response can be associated with static physical properties, Management Zones can be delineated to identify areas within the field that might benefit from customized and target practices such as variations in seed population, hybrid selection, fertility application and chemical based treatments.

There is no single adopted method for delineating Management Zones. In many cases these are subjectively defined based on prior normalized crop performance measured though yield monitors or NDVI imagery. OMAF/MRA research has demonstrated that crop productivity is highly correlated with landscape convexities and concavities. Areas that are prone to moisture and nutrient/organic loss such as the crest of hills will tend to have poorer performance that those areas where moisture and nutrients are less limiting. Regardless of how the Management Zones are delineated, pedological differences such as texture, pH, soil type etc. between Management Zones of the same yield potential and topographic class may exist. The **Smart Soil Sampling** (Triple-S) application will aid in building knowledge of these characteristics and this will aid in the development and evaluation of prescriptions.

Using the **Smart Soil Sampling** (Triple-S) application, a User will have the ability to visualize Management Zones and on-farm generated field data such as yield, NDVI and elevation to aid them in the selection of GPS soil sampling sites. The application will guide them to the selected site where they will collect soil for laboratory analysis, GPS registered photographs and enter anecdotal data using structured dialogs.

Through this Triple-S app, agriculture practitioners will be able to document the site, soil and crop characteristics of good yielding areas and bad yielding areas. In bad yielding areas the crop scout would record the GPS coordinates of the inspection point, photographic evidence would include, for example, the condition of the crop population, crop colour, crop height, insect damage, nutrient deficiencies, vigour, the amount of residue on the surface, the colour of the soil surface, presence of stones - size, concentration - anything which will help explain the reasons for poor performance. If the soil is examined one might use an auger or probe to examine soil characteristics at various depths. Characteristics such as depth or thickness of the top soil, the colour of the top soil, rooting structure, soil structure, depth to compaction, depth to the parent material (tested with 10% HCl acid solution), soil series and soil texture of the plough layer are all examples of the type of data that would be collected with the **Smart Soil Sampling** (Triple-S) application.
The processing algorithms for reclassifying the input layers has been completed and tested. Figure 11 below illustrates an example where an input layer representing a NDVI vegetation image in Jpg format has been selected for a 4 class reclassification. The image in the right panels displays the resulting classified image which then becomes an input layer for the overlay modelling component.

Reclassification to 4 pixels groups

![Classify image](image)

(Original: left, Recolored: right)

![Figure 11. TRIPLE-S - IMAGE RECLASSIFICATION](image)

Once the input layers have been reclassified, they will be overlaid to generate a “unique conditions” map were each class on the map represents a unique set of input layer classes as illustrated in the table below:

<table>
<thead>
<tr>
<th></th>
<th>Slope A</th>
<th>Slope B</th>
<th>Slope C</th>
</tr>
</thead>
<tbody>
<tr>
<td>NDVI 1</td>
<td>A1</td>
<td>B1</td>
<td>C1</td>
</tr>
<tr>
<td>NDVI 2</td>
<td>A2</td>
<td>B2</td>
<td>C2</td>
</tr>
<tr>
<td>NDVI 3</td>
<td>A3</td>
<td>B3</td>
<td>C3</td>
</tr>
<tr>
<td>NDVI 4</td>
<td>A4</td>
<td>B4</td>
<td>C4</td>
</tr>
</tbody>
</table>

The unique conditions map will then be reclassified based on groupings defined by the User. The resulting reclassified map will delineate the sample zones which will be used to group soil sample collections.