BGSTECH Lunch Seminar–V

Nandkishor Dhawale,

PhD. Candidate and PASS research team member
Department of Bioresource Engineering

Research Advisors
Dr. Viacheslav I. Adamchuk
Dr. Shiv O. Prasher

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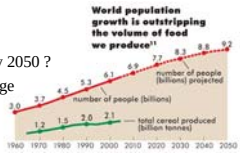
Topics of the talk

1. Background and Introduction
2. Proximal Soil Sensing
   i. On-the Go Soil Sensing
   ii. On-the-Spot Soil Sensing
3. Research Objectives
4. Highlighting Results on
   i. Combining Soil Sensor Information
   ii. Automated On-the-Spot Analyser
   iii. Sensing with Soil Spectroscopy

Background

✓**Food challenges**

- Food availability for 9 billion people by 2050 ?
- Increasing fertilizers and chemicals usage



✓**Environmental impacts**

- Nutrient loss by leaching and runoff
  - Cyanobacteria/algae bloom

✓**How much to apply Dilemma?**

- Low application → **Nutrient Stress**
- High application → **Cost and Pollution**

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Image source: http://images.google.com/

Introduction

Site specific management (SSM)

- **Divide fields** into **parts** called **management groups**
  -Ex. soil type, field elevation data, historical information, etc..

Measurement of soil attributes

- Conventional techniques
  - Laborious and time consuming
  - Poor representation (1 sample/ha.)
  - Can more samples justify the cost

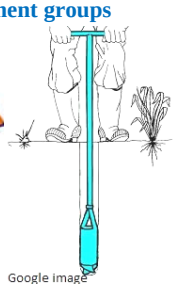

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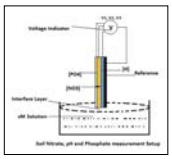
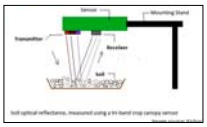
Image source: http://images.google.com/

Proximal Soil Sensing (PSS)

The term *PSS* is used when field-based sensors are used to obtain signals from the soil, placing the sensor's detector in contact with or close to (within 2 m) of the soil. (Viscarra Rossel and McBratney, 1998; Viscarra Rossel *et al*., 2010).

With advancements in Global Navigation Satellite Systems (GNSS) such as the Global Positioning System (GPS), soil information can be collected at resolutions <1-2 cm horizontally and about a twice of it vertically.

Proximal Soil Sensing (PSS)

Electrical Conductivity/Resistivity	Potentiometry	Spectroscopy
		
Indirect measurement	Direct measurement	Direct/Indirect measurement
Measured Soil Properties:	Measured Soil Properties	Measured Soil Properties:
• Texture; % Sand, % Clay and % Silt • Cation exchange capacity (CEC) • % Soil organic matter (SOM) • Soil organic carbon (SOC) • Soil water content (SWC) • Soil acidity (pH)	• H^+ • NO_3^{-1} • K^+ • Na^+ • HPO_4^- and $H_2PO_4^{2-}$	• Soil minerals • Texture; % Sand, % Clay and % Silt • % Soil organic matter (SOM) • % soil organic carbon (SOC) • Total organic carbon (TOC) • Total nitrogen (TN) • Extractable Phosphorus ($P_{Mehlich3}$)

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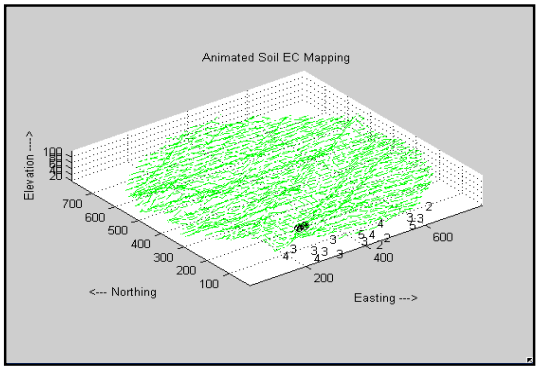
On-the-Go Soil Mapping



On-the-Go Soil Mapping

Rapid and dense mapping

High resolution maps

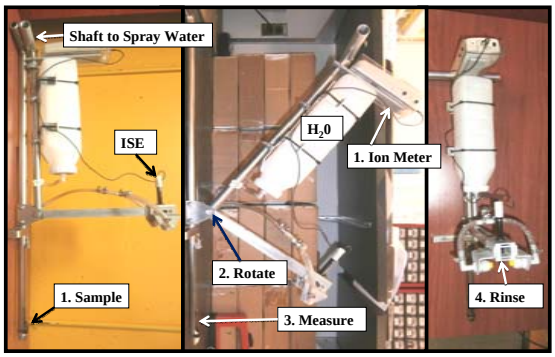
A lot of data to be processed !

Images Source: http://www.veristech.com/products/soilec.aspx

Disadvantages

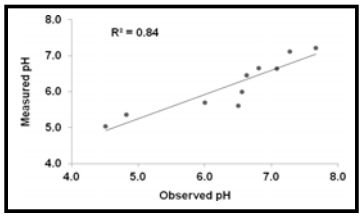
- Soil distortion is created along the entire path travelled.
- Response time of the sensor can be a limiting factor on the time allowed for each measurement.
- What if field surface coverage does not allow for the continuous engagement between soil and parts of the sensor system.

The Instrumented Probe



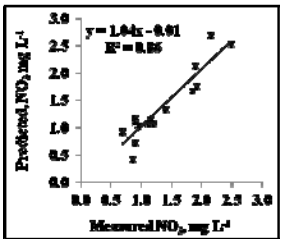
Soil pH

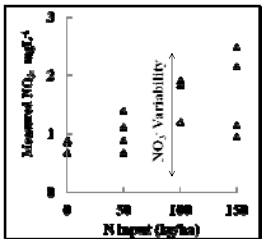
Ten locations from seven plots, on the campus seed farm's research facility (McGill University, Macdonald Campus, Ste-Anne-de-Bellevue, QC, Canada) were chosen to conduct the field evaluation.



Soil NO_3^-

Canola field divided into sixteen plots, which were treated with different levels of urea. Two months after planting, three random in-situ measurements were taken at a depth of 2-3 cm below soil surface.





Dhawale, N.M., V.I. Adamchuk, S.O. Prasher, J.K. Whalen, L. Pan and A.S. Mat Su. 2013. Rapid measurement of nitrate ion activity using a direct soil sensing approach. *In: Soil Science: The Centre of It All. Proceedings of CSSS/MSSS/CSAFM Joint Meeting*, Manitoba, Winnipeg, 22-25 July 2013, 99 (published abstract).

Disadvantages

• Need of operator.

• What if it is very crucial to collect soil samples or sensor based measurements without delays (on time) where data misinterpretation and financial losses are undesirable.

• Else if in harsh and hazardous environments, where health of human labour is at risk.

• What about exploring automation/robotic solutions?

Mars Rovers

List of well-known Mars Rovers

1. Sojourner, 1997-97
2. Spirit, 2003-10
3. Opportunity, 2004-12
4. Curiosity, 2011-present

Soil Mapping System (None)

- Simpler than the Mars Rover.
- Affordable to a North American farmer.
- Robust to operate in uneven field surface conditions.

Image Source: http://marsrovers.jpl.nasa.gov/home/index.html

Interesting Ag-Rovers

• **No Unmanned Agriculture Soil Mapping Systems**

http://www.unibots.com/Agricultural_Robotics_Portal.htm

Challenges

Several challenges over choosing or developing a suitable.

• Platform of mobile vehicle, capable to operate in uneven field surface conditions.
• Platforms for soil sensor data acquisition.
• Strategies to collect multi soil information.
• Algorithm's to combine soil sensor information.
• Human safety and security.

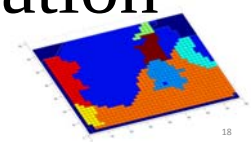
All above keep the research plate burning hot in this discipline!

Research Objectives

The overall objective of this research is:
•To develop an Automated On-the Spot Analyser (OSA)

The specific objectives are:
1.To develop a methodology for the hierarchical clustering of high-density, multi-source, proximal-sensing soil data such as Field Elevation and Soil Electrical Conductivity.
2.To develop and evaluate a autonomous platform capable to determine H^+ and NO_3^- ion activities on-the-spot.
3.Analysing the capabilities of advanced Vis/NIR/MIR spectroscopic instruments, for detecting differences in selected soil properties towards extending the suit of deployable sensors, on the platform.

Combining Soil Sensor Information



Present Choices

Majority of known algorithms

➢Relate to Kmeans clustering.

➢ Which calculates a distance matrix based on data and performs clustering over this new distance matrix and they doesn't consider the spatial distances.

➢ The results depends on the selection of initial centroids and therefore not repeatable and requires cross validation.

➢ Complexity and frequently occurring discontinuities of certain management groups make this technology less appealing to potential users.

A New Algorithm Using Neighbourhood Search Analysis(NSA)

1. The default set of group is average of all data points and is called the default of the field.

2. Minimum new group size is defined considering a location with all eight immediate neighbours.

3. A new group can only initiate and grow if the new statistic is lower than the previous statistic, both, calculated over the old and new groups.

NSA

Objective function (the statistic)

$$MSE = \sum_{j=1}^{k} \sum_{i}^{N_k} \frac{\left(X_{ij} - \dot{X}_j\right)^2}{N_k - k} \quad \textbf{(eq. 1)}$$

MSE = mean squared error
X_{ij} = i[th] cell value from j[th] group
$\dot{X}_j$ = averaged cell values from j[th] groups
k = the number of groups
N_k = number of cells within k groups

Performance indicators

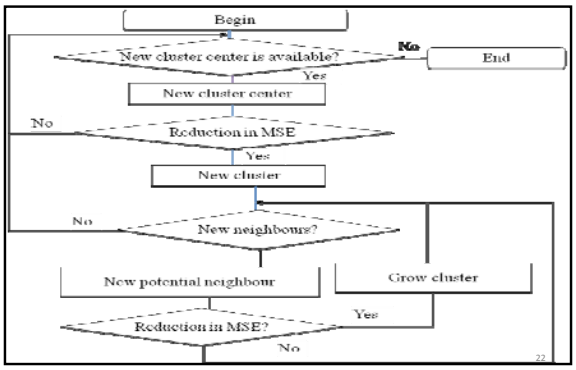
$$R_l^2 = 1 - \frac{MSE_{lk}}{MSE_l} \quad \textbf{(eq. 2)}$$

R^2_l = coefficient of determination considering the lth layer
MSE_{lk} = MSE considering all groups
MSE_l = MSE considering the default group.

$$C_{coeff} = \prod_{l=1}^{3} R_l^2 \quad \textbf{(eq. 3)}$$

C_{coeff} = Comparison Coefficient

NSA



NSA

PROPERTIES	Field 1	Field 2	Field 3	Field 4	Field 5	Field 6
LONGITUDE	-97.984	-98.255	-102.53	-97.572	-98.167	-98.356
LATITUDE	41.2747	40.8882	41.5547	42.1921	40.8427	42.4079
AREA, Ha	25.4	46.08	49.88	54.56	66.84	44.24

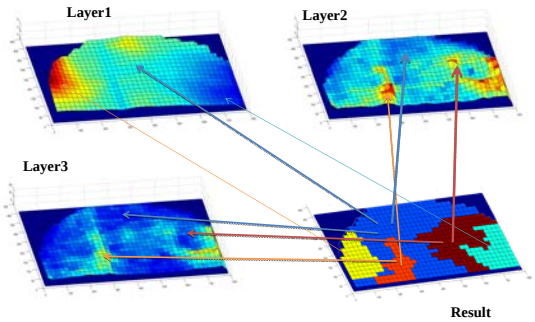
Field Elevation (Elev)
Apparent Soil Electrical Conductivity from both layers shallow (sECa) and deep (dECa) *

RTK based GPS
Galvanic contact disks

Images Source: http://www.veristech.com/products/soilec.aspx

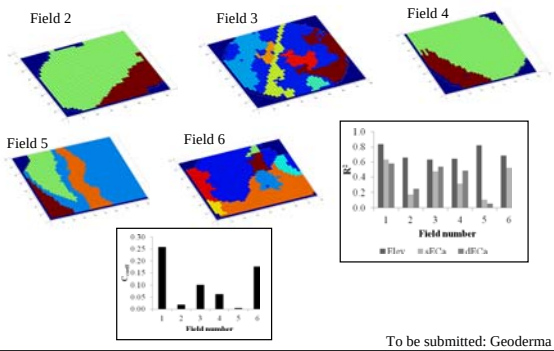
*Dhawale, N. V. I. Adamchuk, S.O. Prasher, and P.R.L. Dutilleul. 2012. Spatial data clustering using neighborhood analysis. Paper No. 12135?2030. St. Joseph, Michigan: ASABE (unpublished abstract).

NSA



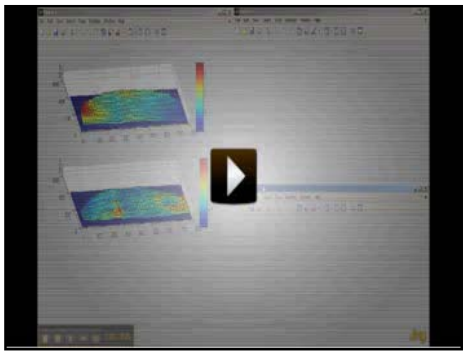
Dhawale, N.M., V. I. Adamchuk, S. O. Prasher, P. R. L. Dutilleul, and R. B. Ferguson. 2014. CONSTRAINT BASED MULTIDIMENSIONAL SPATIAL DATA CLUSTERING OF GEOSPATIAL SENSOR MEASUREMENTS. *In SPIE/IGU from International Conference on Geospatial Data: Processing, Modeling and Applications, 6–8 October 2014, Toronto, Canada*, Paper No. MS#TO-137 (to be submitted).

NSA



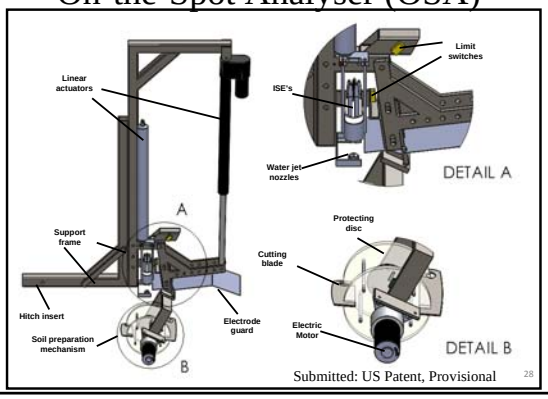
To be submitted: Geoderma

NSA



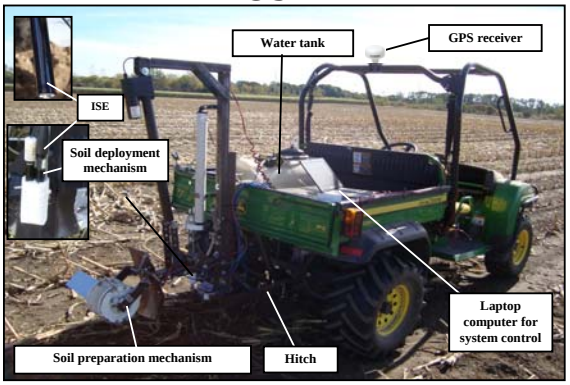
Automated Soil Sensing Platform

On-the-Spot Analyser (OSA)

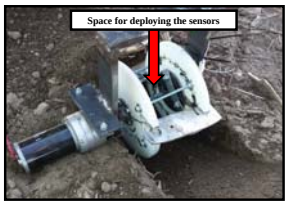


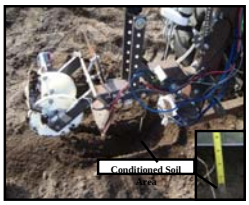
Submitted: US Patent, Provisional

OSA

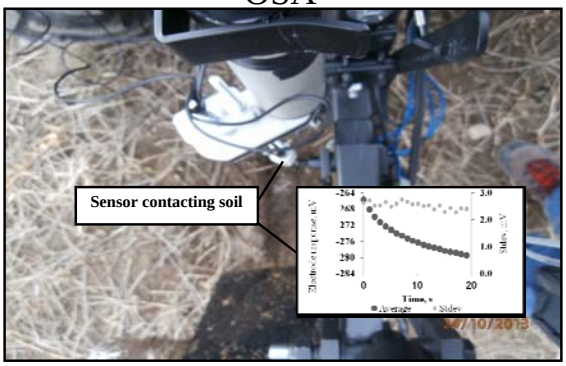


OSA





OSA



V. Adamchuk, N. Dhawale, and F. Rene-Laforest. 2014. Development of an on-the-spot analyzer for measuring soil chemical properties. *In: Proceedings of 12th international conference of Precision Agriculture*. Sacramento, California, USA (abstract accepted).

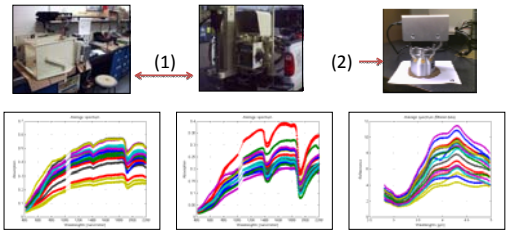
OSA

https://www.youtube.com/edit?o=U&video_id=drLkdepAnec

Soil Sensing with Spectroscopy

Diffuse Spectroscopy

1. Visible-Near Infra Red spectroscopy instrument (VIS-NIR) two fixed ranges; 400-1000 nm and 1100-2200 nm
2. Diffuse Reflectance Mid Infrared (MIR) spectroscopy instrument with a Variable Filter Array (VFA) of two possible ranges; 2780-5096 and 5098-11000 nm



Dhawale, N., V. Adamchuk, S. Prasher, A. Ismail, and R.A. Viscarra Rossel. 2013. Analysis of the repeatability of soil spectral data obtained using different measurement techniques. *In: Proceedings of the 3rd Global Workshop on Proximal Soil Sensing*. Pecora Conference, St. Louis, MO, 29 May-2 June 2013. eds. R. Gebbers, E. Lück, and J. Dabney. 213-215. Potsdam, Germany. ATB Leibniz Institute for Agricultural Engineering Bornim.

Numerous Studies

1. Vis-NIR vs portable MIR using 282 soils.
2. Evaluating a portable MIR on 44 moist soils.
3. *Ex situ*, Vis-NIR using 86 soils.
4. *Ex situ* Vs *In situ*, using Vis-NIR using 20 soils.

1. Texture; % Sand and % Clay
2. Soil Organic Matter (SOM)
3. Soil Organic Carbon (SOC)
4. Soil Total Phosphorus (STP)

Methodology

Soil spectral data was collected in three replicates.

Spectral data was portioned into training and testing sets.

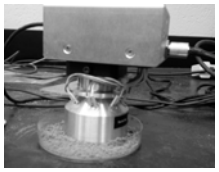
Calibrated models using testing set against laboratory measurements.

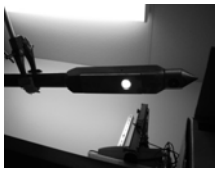
Models validated using leave-one-out cross validation on the training set and directly on the testing sets.

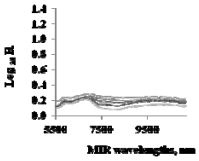
Performance indicators :

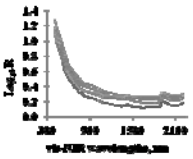
Coefficient of determination (R^2), Root Mean Squared Error (RMSE), Standard Distribution of Errors (SDE), Mean Error (ME).

Study-1

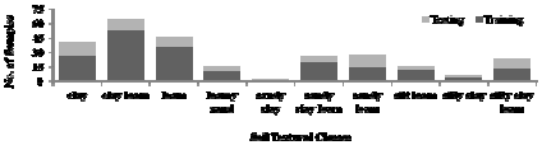








Vis-NIR vs portable MIR



Data set	Stats	Sand, %	Clay, %	SOC, %
Training	Min	0	4	0.54
	Max	86	74	3.91
	Mean	38	29	1.71
	SD	20	14	0.60
	Median	34	28	1.60
Testing	Min	0	5	0.97
	Max	86	75	3.75
	Mean	37	30	1.76
	SD	24	16	0.61
	Median	33	28	1.59

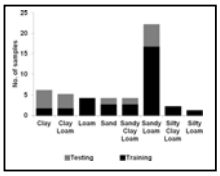
Vis-NIR vs portable MIR

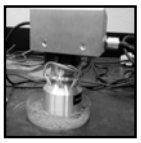
Property, %	Data Set	No. of factors	R^2	RMSE	SDE	ME
Sand	Training	5	0.64	12.14	12.17	0.05
	Testing		0.62	10.33	10.32	1.20
Clay	Training	4	0.61	8.86	8.88	-0.03
	Testing		0.78	7.79	7.80	-0.25
SOC	Training	6	0.63	0.37	0.37	0.00
	Testing		0.54	0.41	0.42	-0.02

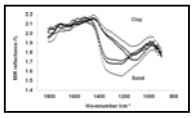
Property, %	Data Set	No. of factors	R^2	RMSE	SDE	ME
Sand	Training	15	0.74	10.40	10.40	0.14
	Testing		0.72	12.73	12.40	-0.05
Clay	Training	7	0.79	6.57	6.58	-0.02
	Testing		0.81	7.17	7.19	-0.35
SOC	Training	12	0.62	0.38	0.38	-0.01
	Testing		0.49	0.45	0.45	0.03

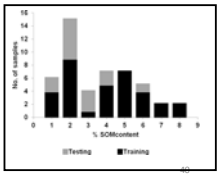
Dhawale, N.M., V.I.Adamchuk, S.O.Prasher, R.A.Viscarra-Rossel, A.A. Ismail, J.K. Whalen & M.Lessargant. 2014. Comparative analysis of vis/NIR/MIR hyperspectrometry for measuring soil physical properties. July 13 – 16. ASABE and CSBE/SCGAB Annual International Meeting. Montreal, Quebec, Canada. (to be submitted).

Study-2







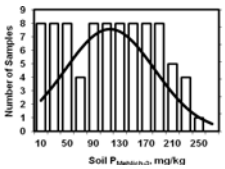


Portable MIR on Moist Soils

Soil sets used for Model calibration	Model validation	PLSR Factors	R^2	RMSE	ME	SDE
		% Sand				
Air-dry training	Cross validation	3	0.74	11.81	-0.03	11.81
Moist training	Cross validation	5	0.81	10.12	-0.04	10.15
Air-dry training	Air-dry test set validation	3	0.90	8.58	-2.10	8.41
Moist training	Moist test set validation	5	0.82	11.65	-4.30	10.89
Moist training	Air-dry test set validation	5	0.80	11.98	-3.70	11 .53
Air-dry training	Moist test set validation	3	0.88	10.26	2.34	10.05
		% Clay				
Air-dry training	Cross validation	3	0.65	9.48	-0.93	9.52
Moist training	Cross validation	5	0.79	7.27	-0.03	7.29
Air-dry training	Air-dry test set validation	3	0.88	10.50	-5.35	9.14
Moist training	Moist test set validation	5	0.91	7.82	-2.57	7.43
Moist training	Air-dry test set validation	5	0.84	9.32	-2.63	9.05
Air-dry training	Moist test set validation	3	0.89	10.06	-5.37	9.55
		% SOM				
Air-dry training	Cross validation	6	0.54	1.42	0.00	1.43
Moist training	Cross validation	6	0.49	1.48	0.01	1.49
Air-dry training	Air-dry test set validation	6	0.58	1.17	0.72	0.93
Moist training	Moisttest set validation	6	0.62	1.21	0.84	0.87
Moist training	Air-dry test set validation	6	0.82	0.76	-0.46	0.61
Air-dry training	Moist test set validation	6	0.43	2.24	0.57	1.07

Study-3

Material and Methods

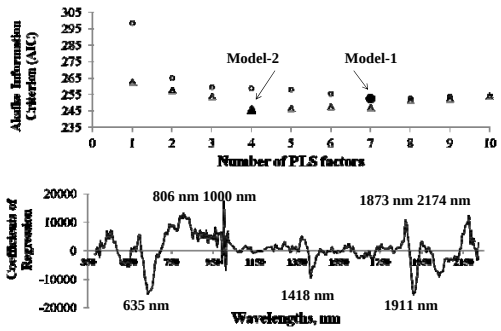


Number of samples	Texture	Depth cm	Minimum	Mean	Maximum	Standard Deviation
31	silty- loam	0-15	96*	177*	244*	38*
33	sandy-silty- loam	15-30	44*	109*	196*	40*
22	sandy-clay	30-60	4*	32*	154*	32*

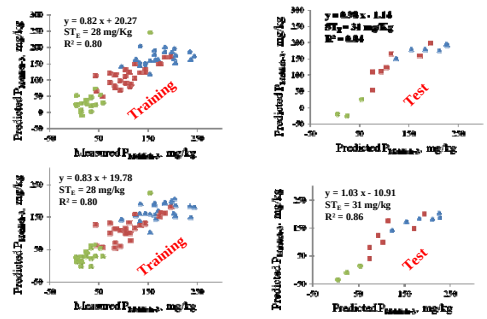
Number of samples	Set	Minimum	Mean	Maximum	Standard deviation
70	Training	4*	112*	244*	67*
16	Testing	4*	127*	228*	71*

* Values of P Mehlich-3, mg/kg

Ex situ, vis-NIR to Predict STP

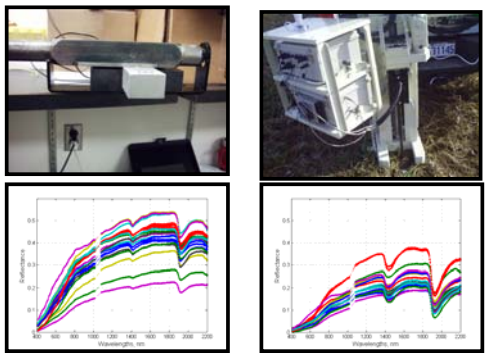


Ex situ, vis-NIR to Predict STP

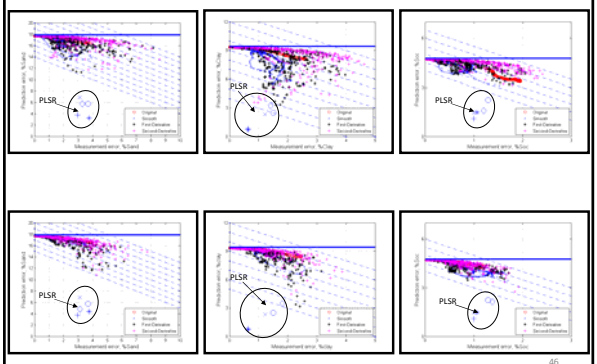


Dhawale, N.M., V.I. Adamchuk, R.A. Vincarra Rossel, S.O. Prasher, J.K. Whalen, and A.A. Ismail. 2013. Predicting extractable soil phosphorus using visible/near-infrared hyperspectral soil reflectance measurements. Paper No. 13-045. Ottawa, Ontario: CSBE.

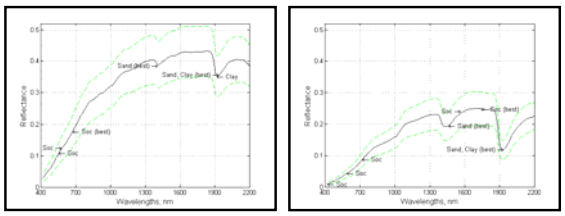
Study-4



Ex situ Vs *In situ*, *Vis-NIR*



Ex situ Vs *In situ*, *Vis-NIR*



Dhawale, N.M., V.I. Adamchuk, S.O Prasher, and R.A. Vincarra Rossel. 2014. Accuracy, Precision and Repeatability of VIS-NIR Hyperspectral Soil Reflectance Measurements. COMPAG (in In Submitted).

Unmanned On-The-Spot Analyser (OSA)

Selected Specifications:

- Video system
- Obstacle detection: F/R
- Comn. : Wired and wireless
- Navigation: RTK-GPS
- Customer specific payload
- Drive: 4WD
- Alternator : 180 A
- Ground speed: 8 Km/Hr

http://www.deere.com/eps/dcom/en_US/products/equipment/gator_utility_vehicles/military_utility_vehicles/r_gator/r_gator_series.page

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NSERC CREATE ISS-Travel Award, 2011-12; L & D Stewart Fellowship, 2011-12 ;Walter M Stewart Scholarship, 2013-

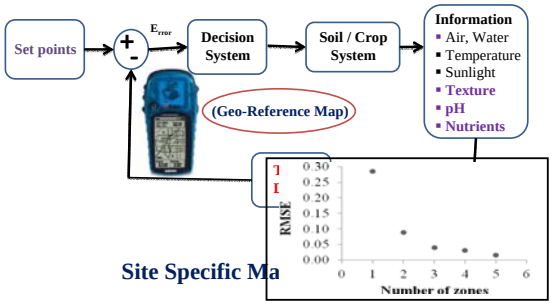
Engineering Questions

✓**Field classification**
- Navigation and sampling/sensing strategies.
- Multidimensional spatial data clustering.

✓**Sensor**
- Type, number, suitability, stability and repeatability.

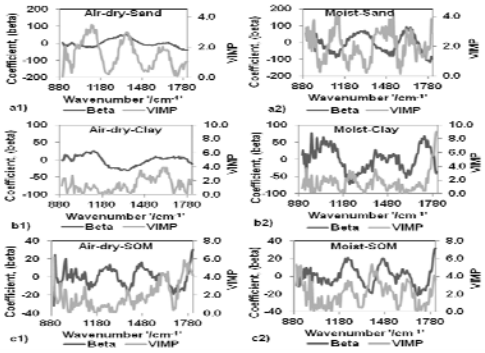
✓**Integrated sensing platform**
- Sizing of hardware and DAQ components.
- Real-time data processing tools.
- Communication between vehicle and sensing platforms.

Introduction



Images: source: Dhawale, N.M.

Portable MIR on 44 moist soils



Dhawale, N.M., V.L. Adamchuk, S.O. Prasher, R.A. Viscarra Rossel, A.A. Ismail & J.Kerr. 2014. Proximal soil sensing using a new portable mid-infrared spectrometer. EJSS. (Submitted).