Predicting Soil Bulk Density in Boreal Podzolic Soil using Ground-Penetrating Radar and Electromagnetic Induction

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Introduction

- **Tillage** and **soil compaction** - influence soil properties, state variables, and processes, ultimately affecting soil health, crop growth, and yield [1,2]
- **Bulk density** and **penetration resistance** - indicators of soil compaction [1-4]
- **Ground-penetrating radar (GPR)** and **Electromagnetic Induction (EMI)** – utilized to estimate soil properties and state variables in the agricultural landscape [5]
- GPR and EMI – lack of studies examining the **bulk density change** associated with tillage and soil compaction

Objectives

1. Evaluate the impact of bulk density change on dielectric constant (K_r) and direct ground wave amplitude (A_{DGW}) measured from GPR, and apparent electrical conductivity (EC_a) measured by EMI
2. Assess the predictive capability of GPR and EMI for bulk density determination

Method

Field data collection

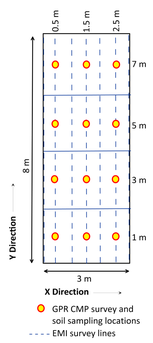

Fig. 1: Field sketch

Three stages → After tillage (**NP**) → After 4 roller passes (**4P**) → After 10 roller passes (**10P**)

Fig. 2: Soil compaction with a lawn roller

Two instruments

EMI sensor CMD–MiniExplorer

GPR system pulseEKKO Pro

Fig. 2: Proxy data collections with a) EMI survey, and b) GPR common mid-point (CMP) survey

Soil sampling → Bulk density – Undisturbed soil samples
3 depths (0 – 10 cm, 10 – 20 cm, and 20 – 30 cm)

Data analysis

- **Correlation –** Proxies and bulk density
- **Random Forest –** Identify variable importance
- **Regression models –** Development and evaluation

Results

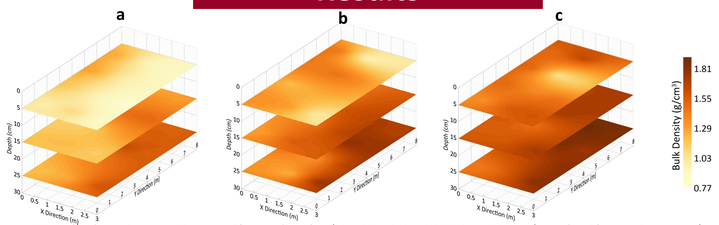

Fig. 3: *Bulk density variation in three depths (0 – 10; 10 – 20; 20 – 30 cm) under three stages, a) after tillage (NP), b) after 4 roller passes (4P), and c) after 10 roller passes (10P)*

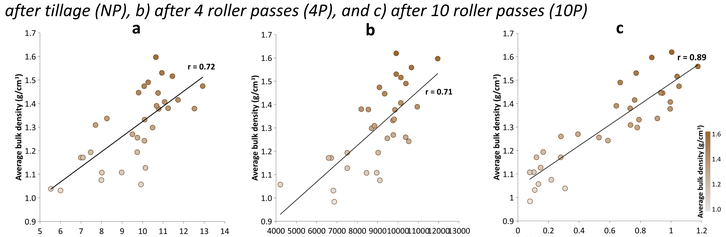

Fig. 4: *Correlation between average bulk density (0-30 cm) and a) dielectric constant estimated from GPR, b) direct ground wave amplitude of GPR, and c) apparent electrical conductivity measured from EMI*

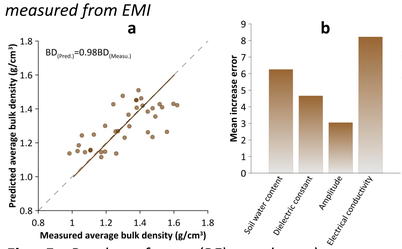

Table 1: *Regression equations, coefficient of determination (R^2), and root mean square error (RMSE), of developed regression models*

Regression Equation	R^2	RMSE (g/cm³)
BD =1.043 + 0.418 EC_a	80	0.075
BD = 0.7840 + 0.05612 K_r	63	0.090
BD = 0.93 + 0.0212 K_r + 0.2734 EC_a	83	0.062

Fig. 5: *Random forest (RF) results: a) scatter plots of measured vs predicted bulk densities with the RF model, and b) variable importance.*

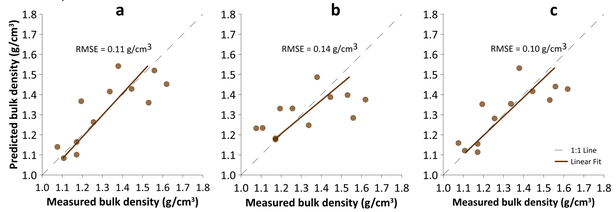

Fig. 6: *Scatter plots of measured soil bulk density and simple linear regression (SLR) and multiple linear regression (MLR) model predicted soil bulk density. SLR model predicted; a) apparent electrical conductivity, b) dielectric constant and c) MLR model predicted.*

Conclusions

- GPR and EMI
  - responded to the applied soil compaction
  - showed **strong positive correlations** with measured average bulk densities
- Compared to the GPR, EMI is found to be better for predicting bulk density in the studied site
- GPR and EMI can **replace point-scale measurements** to estimate soil bulk density **non-destructively**
- The effect of agricultural practices on soil bulk density and its related properties can be estimated and mapped non-destructively using **GPR** or **EMI**, leading to **advancements in precision agriculture**

Key References

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