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GAMMA SOIL SURVEYS – INVESTIGATING SOIL PATTERNS FOR NUTRIENT AND WATER MANAGEMENT

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Abstract

Real-time modelling and management of drainage events is a challenging research topic for New Zealand's soil scientists, because it is a spatially and temporally variable process.

A new gamma soil survey system is being trialled to investigate its potential to collect fine-scale soil information rapidly and affordably, to improve dynamic management and modelling of nutrients and water in soil. The system consists of a GPS-enabled gamma sensor mounted on a quad bike, with an on-board information system to collect soil geophysical survey data.

We conducted a gamma survey pilot study at Massey University No.1 Dairy Farm (160 ha) in 2015. Four maps, corresponding to the four channels of the instrument (Total counts, Potassium, Uranium, Thorium) were produced at 5-m resolution from the survey data. These maps were used along with an existing soil electrical conductivity (EC) map derived using electromagnetic (EM) sensor surveying (5-m pixels) to investigate relationships of sensor data with a soil drainage sequence (rapid, well, imperfectly, poorly drained).

Total gamma counts differed for the soil types, and the relationship of gamma counts to drainage sequence was complicated by varying degrees of soil development. The young Parewanui silt loam soil (Recent Gley) tended to have lowest gamma counts. The older, imperfectly drained Turitea silt loam soil (Mottled Fluvial Recent) had highest total gamma counts. In comparison, soil EC increased linearly with textural fineness and wetness.

This pilot study suggests gamma and EM sensors provide different and complementary data that can potentially be used to refine statistical analyses of soil differences that relate to drainage pathways.

Introduction

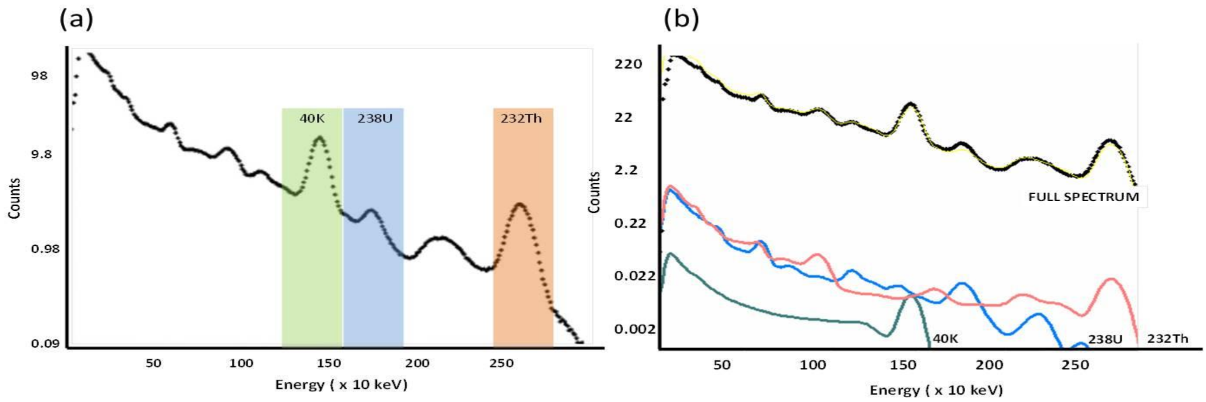
Improved methods are required for real-time management and accurate modelling of spatially and temporally variable drainage events because they impact on efficient water and nutrient use in these managed soils.

Proximal soil sensors enable high resolution (< 10 m) soil data to be collected rapidly and affordably. These sensors respond to variations in soil features, and the data can be used to predict key soil properties for environmental and agricultural issues (Coulouma et al., 2016).

One example of a proximal soil sensor is the gamma radiometrics sensor that can be mobilised to survey soils rapidly (e.g. Van Egmond et al., 2010; Soderstrom and Ericksson, 2010; Viscarra Rossel et al., 2007; 2013).

The gamma radiometrics sensor detects gamma ray photons that are emitted naturally by the atomic nuclei of certain elements occurring naturally in soil minerals. These photons have discrete energies, characteristic of the radioisotopes from which they originate. While many naturally occurring elements have radioactive isotopes, only potassium (K) and the decay series of uranium (U) and thorium (Th) have long half-lives, are abundant in the environment, and produce gamma rays of sufficient energy and intensity to be measured by gamma-ray spectrometry.

The typical gamma spectrum recorded by this instrument has four 'regions of interest' (ROIs) that are the peaks relating to 40K, 238U, and 232Th and the whole spectrum (total counts), (Fig. 1).



(Adapted from: Van Egmond et al (2008) In Proceedings IUSS 1st Global Workshop on High Resolution Digital Soil Sensing and Mapping, Sydney, Australia)

Fig. 1 The (a) natural gamma spectrum is used to derive values for (b) total counts, potassium (40K), uranium (238U), and thorium (232Th) (*adapted from Van Egmond et al. (2010)*).

In soil surveying, the value of gamma-ray spectrometry lies principally in the fact that different rock types contain varying amounts of these three predominant radioisotopes, as do the soils that weather from them.

Gamma survey data therefore relate to parent material and degree of weathering. This potentially complements electromagnetic (EM) soil survey data, which relate to soil texture and moisture differences in non-saline conditions (Hedley et al., 2004). In contrast with EM sensors, the gamma sensors are suited to surveying dry soils. Approximately 95% of the measureable gamma-radiation is emitted from the upper 0.5 m of the soil profile. Attenuation of gamma rays through soil varies with bulk density and water content. Signal attenuation increases by approximately 1% for each 1% increase in volumetric water content. The half thickness that will reduce radiation (to half its intensity) is 10 cm in soil and 121 m in air.

Ground-based systems have been used to establish relationships between K concentration and apparent topsoil dust accumulation, which were identified as containing appreciable feldspar and illite. Total counts were also used to identify management zones for precision agriculture practices (e.g. Rodrigues et al., 2015). Wong and Harper (1999) identified excellent linear relationships between K concentration measured using gamma radiometrics and soil available K. Pracilio et al. (2003) related gamma radiometrics data to gravel, clay, ironstone gravel and total feldspar content. Ground-based surveys have been shown to give improved relationships with soil properties compared with airborne surveys. They are suited to the investigation of complex soil patterns that relate to mixed parent materials. Wong et al. (2009) showed that while total gamma emissions increased in shallow soils with gravels within the top 45 cm, electrical conductivity (EC) decreased. EM and gamma sensors have the potential to be used simultaneously to improve soil prediction models, using appropriate data fusion methods.

Our aim was to develop a gamma soil survey system, and interpret the data from a pilot study to investigate its usefulness for predicting soil patterns that influence nutrient and water management.

Method

Site description

The study area is the 160 ha Massey University No.1 Dairy Farm. The soils are young, having developed in the flood plain of the Manawatu River, and soil types are defined by the soil survey of Pollok et al., (2003), (Fig. 2).

Soil textures range from loamy gravels and sands through sandy loams and fine sandy loams to silt loams. The alluvium in which these soils have developed is derived from greywacke, and the greywackes are siliceous in composition (typically up to 75%) with quartz, alkali feldspar, and biotite being the dominant minerals.

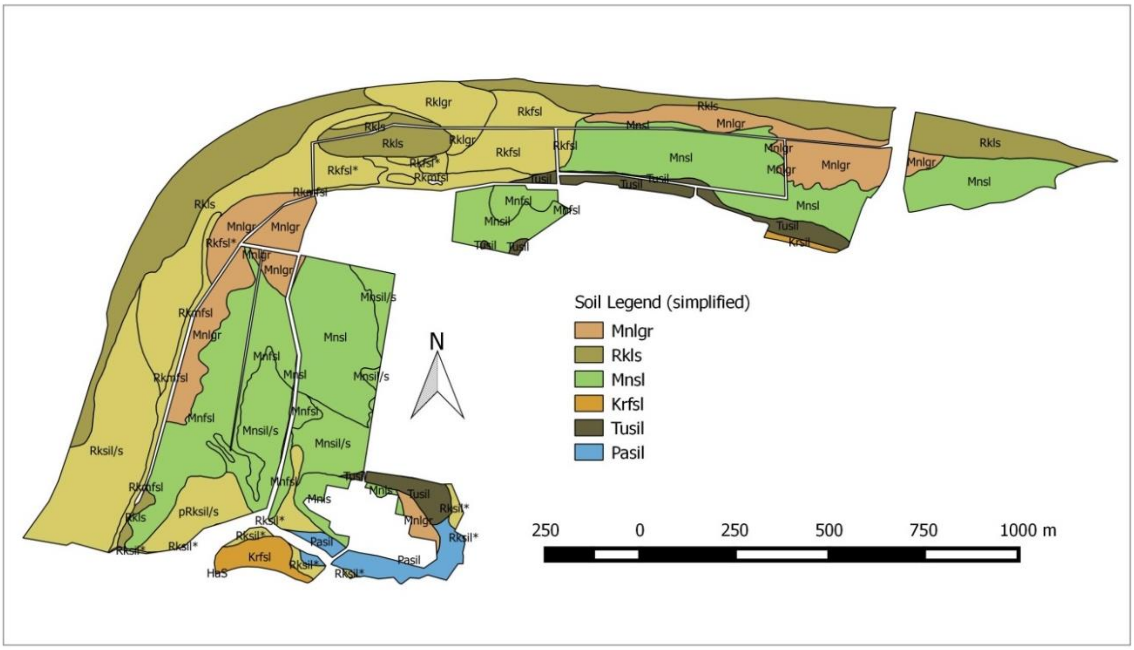


Fig. 2 Soil map of Massey University Dairy No.1 Farm (Pollok et al., 2003).
[Mnlgr = Manawatu loamy gravel; Rkls = Rangitikei loamy sand; Mnsl = Manawatu sandy loam; Krfsl = Karapoti fine sandy loam; Tusil = Turitea silt loam; Pasil = Parawanui silt loam]

Drainage characteristics of the soils at this site, which bounds the Manawatu River, are reported to range from very well-drained loamy gravels, sands and sandy loams, through imperfectly drained sandy loams and silt loams to very poorly drained silt loam soils (Pollok et al., 2003).

For this study the soil drainage classes are defined as:

- well drained (ordered by textural fineness: Manawatu loamy gravel, Rangitkei loamy sand, Manawatu sandy loam, Karapoti fine sandy loam)
- imperfectly drained (Turitea silt loam)
- poorly drained (Parawanui silt loam)

There is also an age sequence from frequently flooded young alluvial soils closest to the river (Rangitikei and Parawanui series), to more developed Manawatu soils on the lower terrace, and older Turitea and Karapoti soils, which occur at slightly higher elevations furthest from the river. These alluvial soils tend to become less freely drained and older with distance away from the river. The Recent Gleys (Parewanui silt loam) are an exception to this rule, as they occur adjacent to a tributary stream in a frequently inundated area.

Gamma soil survey

A mobile gamma soil survey system was used to survey the farm. The system consists of a GPS-enabled gamma sensor mounted on a quad bike, with on-board information system to collect soil geophysical survey data (Fig. 3).

The survey was undertaken over a 13 day period between November 2014 and February 2015.

Fig. 3 Mobile gamma soil survey system

The gamma sensor software was used to convert the logged data to total counts and elemental concentration (40K, 238U, 232Th). The raw gamma point clouds were then pre-processed to remove duplicate data points, and interpolated onto a 5-m regular grid using ordinary kriging in the R statistical environment (R Core Team, 2015). The Matérn variogram model was used to model semi-variance of the data. This model generalises several theoretical variogram models and incorporates a smoothness parameter. It has been found to be flexible and able to describe many isotropic spatial soil processes (Minasny & McBratney, 2005).

The resulting data were then imported into QGIS software to produce maps of the intensity of the ROIs: 40K 238U, 232Th and total counts (Fig. 4). Details about production of the EM map are provided in Hedley & Yule (2009).

Results and Discussion

The four gamma maps (Fig. 4) exhibit similar patterns and align closely with some soil boundaries, for example the extent of the Rangitikei loamy gravels (Fig. 2) as does the EC map (Fig. 5).

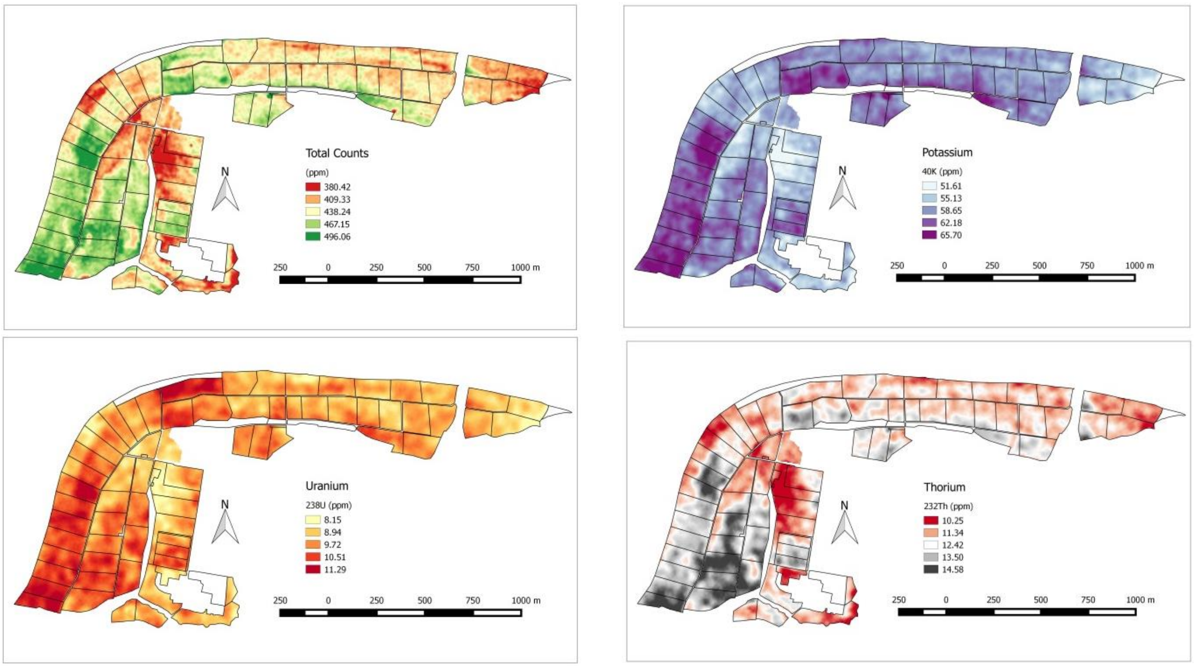


Fig. 4 Maps to show natural gamma emissions from soils, Massey Dairy No.1 Farm

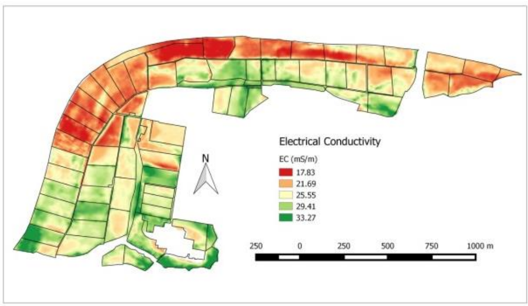


Fig. 5 Soil apparent electrical conductivity map, Massey Dairy No.1 Farm

The maps produced from the four gamma channels and the existing EM survey were used to investigate relationships between sensor data and the soil drainage sequence. To do this we extracted gamma, EM, and soil type data at 100 stratified positions (proportionally sampling the complete range of possible soil drainage differences). The soil drainage classes reflect soil texture and position in the landscape. The well drained soils are loamy gravels, loamy sands, sandy loams, and fine sandy loams, tending to increase in depth over gravels from 10–20 cm to >1 m. The imperfectly drained silt loam soils are slightly older, more weathered soils, occurring on higher surfaces with respect to the river channel. The poorly drained Parawanui silt loam soils occur in low-lying landscape positions close to the river that are periodically inundated by flood waters, with a relatively high water table.

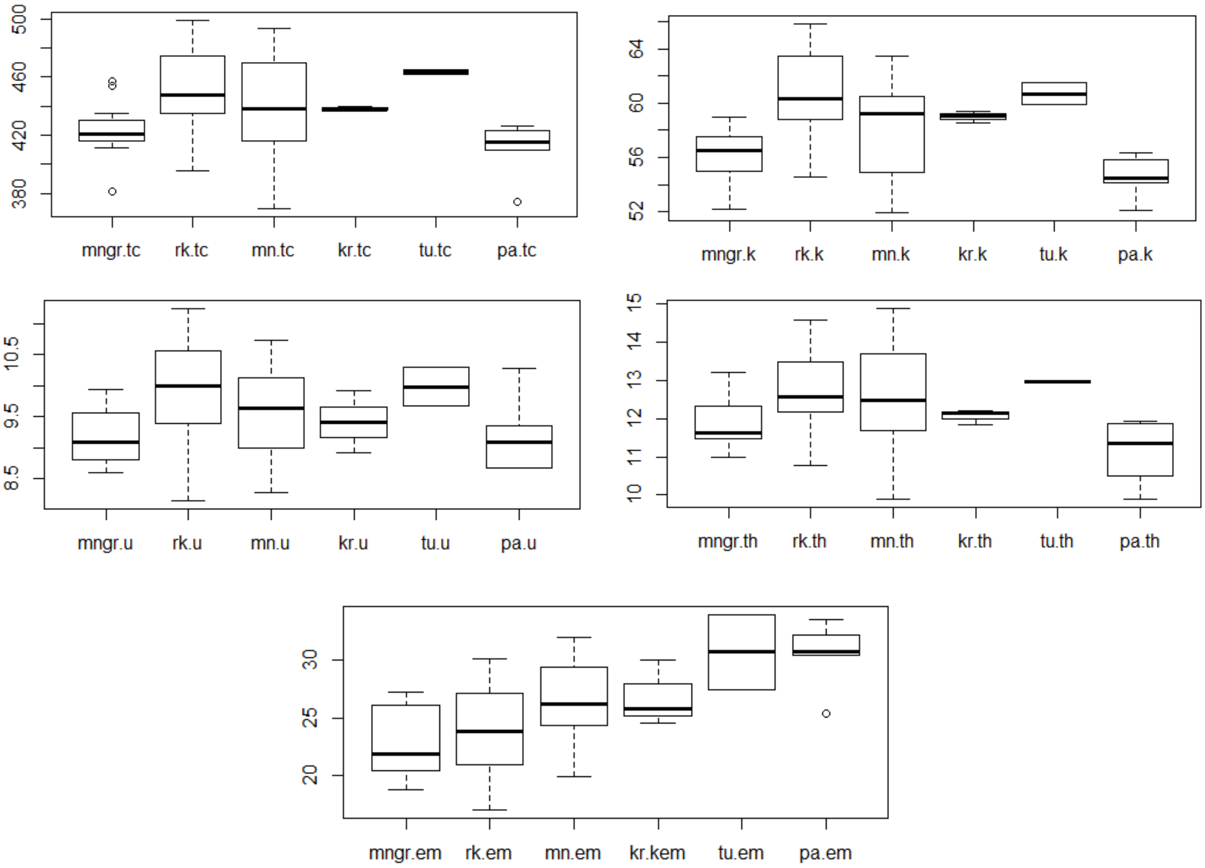


Fig. 6 Relationship between gamma radiometrics, electrical conductivity and soil drainage sequence.
[mngr = Manawatu loamy gravel; rk = Rangitikei loamy sand; mn = Manawatu sandy loam; kr = Karapoti silt loam; tu = Turitea silt loam; pa = Parawanui silt loam]

The gamma values fall within the range reported by Viscarra Rossel et al. (2013) for a 10,000-ha region of Tasmania, using a similar gamma survey system. These researchers report comparatively large emissions of K from freshly weathered alluvial soils compared with older, more weathered soils. At our New Zealand site there is limited opportunity to explore relationships of gamma counts to degree of weathering. Total counts for the Turitea silt loam imperfectly drained soils (Mottled Fluvial Recent Soil) on older surfaces are significantly higher (TC-Turitea = 463.5±1.5) than for the other soils (Fig. 6). This possibly indicates greater weathering in these soils; although this effect is not observed in the Karapoti soils. The Recent Gley soil (Parewanui silt loam) has the lowest total counts (410.6±7.7), potentially due to lack of weathering and wetness.

In comparison, the mean EC values for the soils range between 22.8±0.7 mS/m (Manawatu loamy gravel; Typic Fluvial Recent Soil) and 30.7±3.3 mS/m (Turitea silt loam; Mottled Fluvial Recent Soil) and increase with the drainage sequence, as soil texture becomes finer and drainage becomes poorer (Fig. 6).

Conclusion

Total gamma counts differed for the soil types, but their relationship to drainage sequence was complicated by varying degrees of soil development. The EM survey ranked the soil types in a drainage sequence, with lowest EC values relating to the more rapidly draining, coarser textured soils.

Further research is required to interpret the relationship of each gamma-emitting isotope to soil processes. In addition, future research opportunities for this technology include investigating the use of gamma survey data with and without other high resolution soil data, such as EM and LiDAR (remote sensing light detection and ranging method for sub-meter elevation data), to improve: (i) derivation of management zones for variable rate prescription maps and (ii) spatial modelling of soil attributes, including drainage class, stoniness, clay content, available water storage, and soil organic carbon.

Acknowledgements

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