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Multi Sensor Soil Sensing Tool for Farmland in Spain

F.M. van Egmond (Medusa Explorations) & R.L. Koomans* (Medusa Explorations)

SUMMARY

In the EU LIFE+ project 'Crops for better soil' the aim was to increase the (financial) yield of Spanish farmers on low-yielding rainfed soils and improve the soil itself by applying several agronomic measures and by better understanding the soil itself. Medusa Explorations and Universidad Politécnica de Madrid (UPM) were responsible for soil monitoring and acquiring soil information. To this purpose Medusa developed an efficient and effective soil sensing system (gamma-ray and GPR) on a 4x4 car to be able to measure >100 fields, 300 ha throughout the north of Spain in 3 weeks. The sensing data was combined with open data (DEM, geology) and soil sampling results (by UPM) to acquire information about soil texture, soil organic matter, tillage layer depth, compaction, altitude, slope, nutrients. This provided a good understanding of the soils and is a powerful communication tool for farmers and agronomists.

Introduction

On many rainfed, higher-altitude agricultural fields in the semi-arid regions in the north of Spain, soils are prone to erosion, compaction and low organic matter content. Therefore, these soils suffer from a low nutrient availability and water holding capacity. Together with low precipitation rates this results in low yields and unsustainable farming. The EU LIFE+ project 'Crops for better soil' was initiated to show that with several agronomic measures, the (financial) yields and the soils of these fields could be improved. The project demonstrated this approach on a significant scale by applying these measures on over 100 fields. Together these fields comprise 300 – 400 hectares, spread over the regions Castilla la Mancha (Guadalajara), Aragon, Navarra and Castilla y León (Zamora/Benavente) and these fields are owned by 14-20 different farmers. The agronomic measures include a conversion to organic farming, increasing crop rotation, introduction of leguminosae and introduction of traditional crop varieties that are better adapted to the cold semi-arid climate.

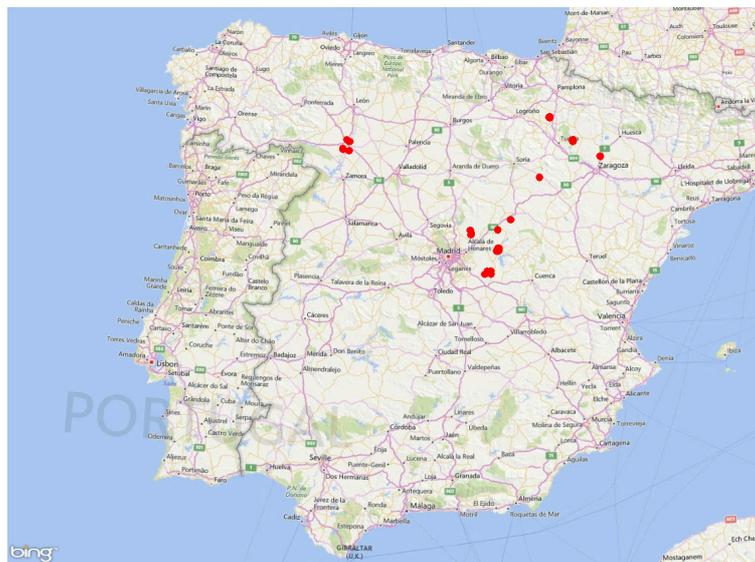


Figure 1 The fields studied were spread throughout the north of Spain (red dots). Source topographic map: Bing.

In order to assess which crops and which rotation are suitable for which field, and to assess improvement of the soil, a soil data acquisition and monitoring plan was designed. Soil and field properties to be assessed are soil texture, soil organic matter, tillage layer depth, compaction, altitude, slope and nutrient concentration. Because the aim was to acquire data on a large set of soil parameters with a good spatial coverage, a combination of traditional sampling and soil sensing was chosen. To facilitate this, Medusa Explorations and Medusa Sensing built a flexible and robust measurement setup on a 4x4 car: the Agribox. This Agribox consists of a gamma-ray spectrometer, a Ground Penetrating Radar (GPR), GPS and integrated logging software. All fields were scanned at the beginning and end of the project. At the beginning and at the end of the project all regions were sampled by Universidad Politécnica de Madrid (UPM). The acquired data was combined with open data from Instituto Geológico y Minero de España (IGME) and analysed on soil properties and soil status.

Soil sensing with the Agribox

The aim of the soil data acquisition plan was to acquire a large set of soil parameters for each field. To achieve this, we combined soil sampling with soil sensing and selected gamma-ray spectroscopy and GPR as suitable sensing techniques to yield relevant results. Since the fields were spread throughout the north of Spain we needed a measurement setup with low set-up times, a high flexibility, robust and suitable for the dry, sometimes steep, stony Spanish fields. To achieve this, Medusa Sensing

developed the Agribox and mounted it on a 4x4 car. The Agribox consists of a MS4000 gamma-ray spectrometer (4 L CsI built by Medusa Sensing), a GPR (500 MHz ZOND), a GPR (Trimble), a connectivity centre and a toughbook. The system is powered by the car engine. The gamma-ray spectrometer is mounted at the front of the car in a custom made steel casing. The GPR is towed behind the car in a sledge. The GPS is positioned on the roof of the car. The system is operated on the toughbook installed in front of the passenger seat of the car. All data is logged simultaneously by in-house developed software. The software allows for quality control of the data and plots a real-time XY map of measured data and current location. This allows for an indicative interpretation of the gamma-ray data in combination with visible soil characteristics, slope and geology of the field. This interpretation, is logged on an iPad.

The robust and easy to use set-up of the Agribox allowed a very short built-up time of 5 minutes per field. This allowed us to measure over 300 hectares of over 100 fields throughout the north of Spain in 3 weeks. The system proved to be robust and able to handle the stony, dusty and dry conditions.



Figure 2 Measurement setup with a gamma-ray spectrometer in front of the vehicle and GPR behind in a carriage the vehicle.

Data acquisition

All fields were scanned with the Agribox in September 2012 and September 2015. UPM took 80 soil samples of 0-10 cm and 10-20 cm depth on conventional and converted project fields in 2012. This measurement was repeated in 2015. The soil samples were analysed on soil texture (clay, silt, sand fraction), organic matter content, pH-H₂O, N, P, K, EC (electrical conductivity), aggregate stability, microbial activity. The MAGNA 1:50.000 geologic map of IGME was used for data interpretation. The MDT05 LIDAR data of IGME were used for altitude and slope.

Data analysis

The gammaspectrometer data is analysed in Gamman software (Medusa Sensing) using full spectrum data analysis (FSA) (Hendriks *et al.*, 2001). The point measurements of ⁴⁰K, ²³⁸U, ²³²Th, ¹³⁷Cs and countrate (total radiation) were interpolated to maps. The regions were stratified on provenance using the geology maps and sample results to assess calibration scale (van der Klooster *et al.* (2011), van

Egmond *et al.* (2010)). The sample results of texture and radiation measurements were used to derive calibrations for clay, silt and sand content based on ^{40}K and ^{232}Th . These calibrations were used to derive texture maps. Furthermore, countrate proved to be a good predictor of overall soil texture variation when visual observations of stoniness patterns were included in the analysis.

The GPR was analysed by using timeslices of 0-20 and 20-80 cm to detect spatial variation in soil structure and differences in depth. The tillage layer on these soils is 10-15 cm depth. This means that most soil compaction will form just below, at 15-20 cm depth. Most variation in the subsoil timeslice can be explained by differences in geology and texture, derived from the geology, altitude/slope and texture maps. Differences between the topsoil and subsoil timeslices is either a difference in tillage layer depth or an indication of soil compaction. The latter is checked by reviewing the GPR images.

The LIDAR altitude data is used to calculate slope of the fields, together with the texture and geology maps this can be useful to determine a risk of erosion. The soil sampling results were used to quantify nutrient availability and study the increase/decrease of soil organic matter content of the fields after 3 years of organic farming. Since we sampled conventional and converted fields we could make a comparison of the soil organic matter content and the microstructure of comparable soils under different agronomic regimes.

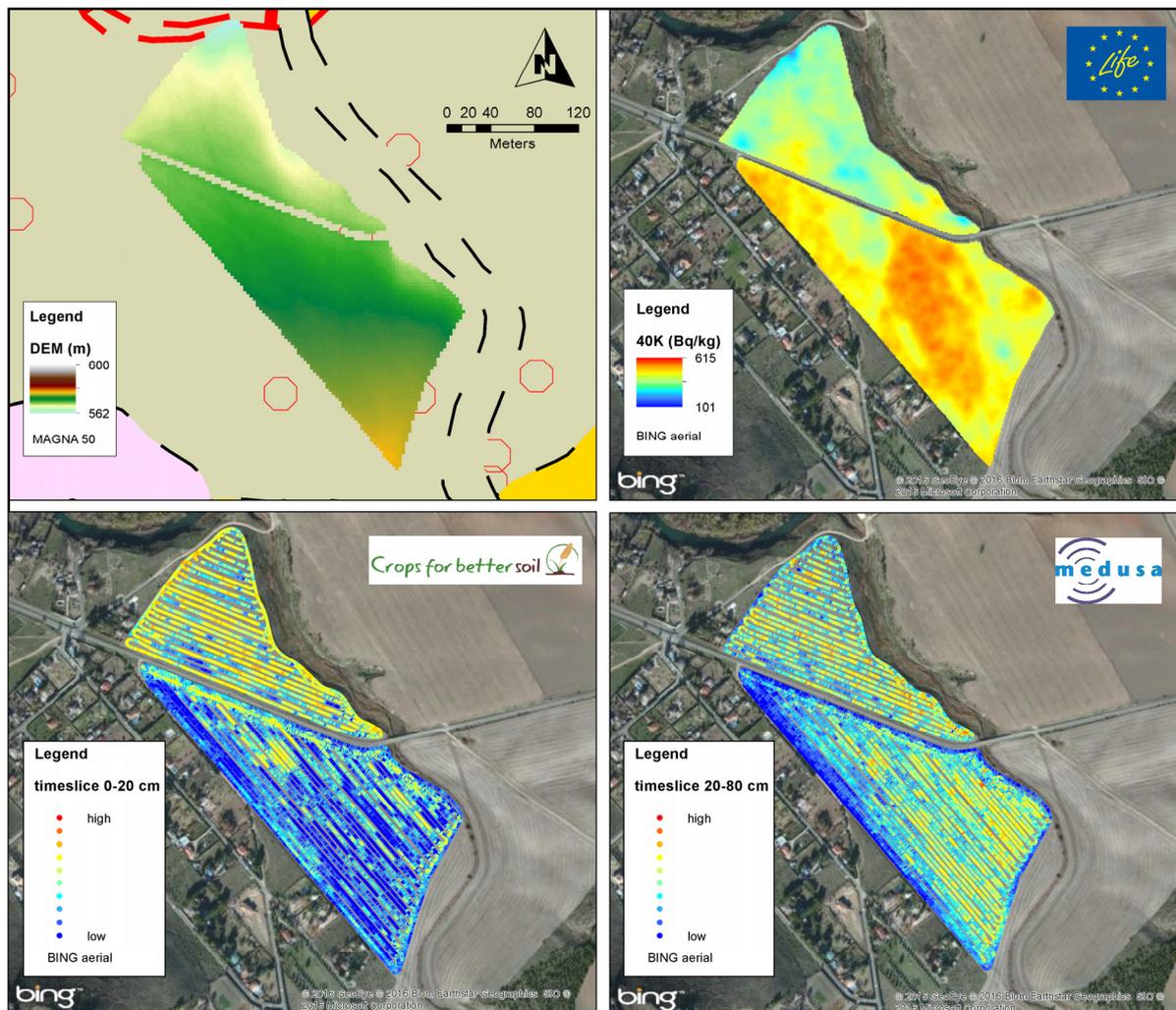


Figure 3 Example of the various data types used. LIDAR DEM (upper left) of IGME, MAGNA 50 geology map of IGME (upper left), concentration of 40K derived from gamma-ray spectrometer (upper right), timeslice 0-20 cm derived from GPR (lower left), timeslice 20-80 cm derived from GPR (lower right). The fields are located near Illana, Castilla la Mancha, east of Madrid.

Example – Illana

The example depicted in figure 3 shows the 6 layers of geophysical and open data used to assess (the variation of) several soil properties as performed in the project. The DEM/DTM shows a slight decline northward but no steep slopes. The aerial photograph shows a small river flowing to the north of the field. The geology of the fields is the same, so we do not expect major differences in parent material. The texture patterns and to some extent the patterns on the timeslices show a consistent pattern on both sides of the road. The redder colours on the texture map indicate a higher concentration of ^{40}K . The calibration shows that higher concentrations of ^{40}K are correlated to a lower sand fraction and a higher clay content. This is validated by soil texture assessment at soil pits in the field. We can conclude that the southern field contains more clay in the topsoil than the northern field.

During measurements we observed a higher concentration of stones in the north of the southern field. This location corresponds with higher reflection values in the 0-20 cm timeslice. Since the higher reflection is also visible in the 20-80 cm timeslice we can conclude that this spot continues below 20 cm. At the north-eastern part of the field we did not observe more stones, indicating a possible compaction. The subsoil on the southern field is more dense than the topsoil and comparable to the subsoil at the northern field. This is expected based on the geology. On the northern field we also observed more stones at the soil surface, thus explaining the higher reflections in the topsoil timeslice.

Benefits and lessons learned

The Agribox, containing a MS4000 gamma spectrometer and GPR proved to be a robust, effective and efficient soil sensing platform, mounted on a 4x4 car. The data acquired in the field provided a useful means of communication between measurement crew, agronomists and farmers. The farmers recognised the patterns in the fields as shown by the geophysical maps from their own experience in working with these fields for many years. This improved their support for soil sensing and improved the discussion between agronomists and farmers about the differences between and within their fields. By semi-quantifying and mapping the farmers' experience soil sensing opens the door to a better understanding of their soils and perhaps the use of more advanced precision farming methods.

The combination of soil sensing, soil sampling, the use of ancillary open data and expert knowledge enabled the (semi-quantitative) derivation of many soil parameters including an indication of soil quality. The use of ancillary data was crucial for the correct interpretation of sensor data.

Outlook

The Agribox system as described in this paper is also applied in a vineyard, orchards and two agro-forestry fields. Data analysis is still ongoing but the first results are promising.

Acknowledgements

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