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SOIL PROPERTIES EVALUATION OF SPATIAL VARIABILITY UNDER PIVOTS IN THE REGION OF EL-MANSOURA, GHARDAÏA DISTRICT, ALGERIA

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ABSTRACT

The productivity of Saharan soils under pivot is largely governed by the heterogeneity of soil properties at the field scale. The present study focused on the assessments of the spatial variability of pH, soil salinity and organic matter using a geostatistical approach, in the study area. Therefore, two pivots were selected, in the Mansoura region in Ghardaïa – district, Algeria. A set of soil samples were taken (20 samples per pivot) at top soil with depth ranging from 0 & 25cm). After soil preparation a series of analyses were carried out on pH, electrical conductivity and organic matter following Walkey-Black method. The results obtained reveal that the soils present an alkaline pH (pH=8.4± 0.1; 8.3± 0.2), the soil are not salty EC (dS/m) =1.52± 0.6; 2.1± 0.7) and have a low or moderate percentage of organic matter (OM% = 0.33± 0.22, 0.23±0.1) in Pivot 1 and Pivot 2 respectively. These results were interpolated by IDW interpolation and the effectiveness of this geostatistical model was evaluated by calculating the mean error (ME) with value (ME= 0.03, -0.02; -0.02, 0.02; 0.03, -0.003) and root mean square error (RMSE) With value (RMSE= 0.11, 0.16; 0.59, 0.72; 0.25, 0.12) in pH, electrical conductivity and Organic Matter in Pivot 1, Pivot 2 respectively. The thematic maps show a strong spatial variability at the scale of the two study areas. This research could be applied to other studies on the factors controlling the dynamics of soil properties in agricultural land, especially in a Saharan environment. It is strongly recommended that this type of study be conducted in Saharan agricultural lands and that it be extended to large-scale regions.

Keywords: pH, salinity, organic matter, spatial variability, geostatistics

INTRODUCTION

Soil is a fundamental resource that supports plant growth and thus ensures the primary production, such agriculture, on which the human population directly depends (Kopittke et al. 2019). Soil is a vital resource, not only for filtering water, supporting biodiversity and sequestering atmospheric carbon (Benslama et al. 2024) but also as a living and fragile environment where intense biological and physico-chemical exchanges and transformations occur (Gros 2002). These dynamic processes make soil essential for ecosystem functioning and sustainability, highlighting the need for its careful management and preservation. The Sahara regions of Algeria cover around two million square kilometres. They are characterised by an arid climate, which is hot for most of the year, making it impossible to grow crops without irrigation (Benslama et al. 2020). Therefore, understanding the spatial distribution of soil properties can contribute both to maintaining better ecological health and to using limited soil and water resources to reduce the pressure of soil degradation. For realising all these, needs and involved the opportunity to help guide farming practices and maintain sustainable vegetable farming development (Boubehziz et al. 2020). Remote sensing, geographic information systems (GIS) and modern instrumental methods could provide a powerful tool for predicting, assessing, monitoring, managing and mapping soil properties such as alkalinity, salinity and fertility (Hasab et al. 2020). Remote sensing, whose information is available at the pixel scale, will be a source of data at the spatial scale over the entire area of the perimeter and at the temporal scale for monitoring the evolution of this phenomenon at the level of the irrigated perimeter. Moreover, geostatistics is considered to be an effective method for interpolating data. Spatial analysis can therefore be used to detect, monitor and map spatio-temporal variations in areas that are vulnerable to or affected by salt (Benslama et al. 2020). Geostatistics, which is a method of spatial analysis and interpolation, will enable us to describe trends and spatial correlations in soil salinity and improve the quality of mapping estimates (Benslama et al. 2020). GIS will enable us to use the data provided by satellite images, of which there will be hundreds of thousands, to analyse, process, map and present them (Boubehziz et al. 2024).

The objective of this study is to assess the spatial variability of key soil properties such as pH, salinity and organic matter in agricultural lands under pivot irrigation systems in the Saharan region. Using geostatistical methods, the research aims to generate thematic maps that highlight the heterogeneity of these properties at the field scale, evaluate the effectiveness of the IDW interpolation model, and provide insights into soil management practices suitable for arid environments. The ultimate purpose is to contribute to a better understanding of the factors influencing soil dynamics in Saharan agricultural systems and support sustainable land use strategies.

MATERIALS AND METHODS

Study area

The study area is presented by an agricultural land (Pivot) (32 ° 06′44.35 ″ -32 ° 06′31.30 ″ North latitude; 3 ° 48′12.54 ″ -3 ° 48′40.02 ″ East longitude and located in Mansoura department, which is a part from Ghardaïa district, in the centre of Algeria (Figure 1). The region of Ghardaïa is characterized by an arid Saharan climate with two distinct seasons: a hot, dry season from April to September and a temperate season from October to March. The daily temperature variation is significant, with amplitudes reaching 15–16°C between day and night. January is the coldest month, with an average minimum temperature of 6.2°C, while July is the hottest month, with an average maximum temperature of 41.8°C. Annual precipitation is low and irregular, ranging from 100 to 200 mm, often occurring as torrential rain. The annual evaporation rate exceeds 2.000 mm (ONM 2017).

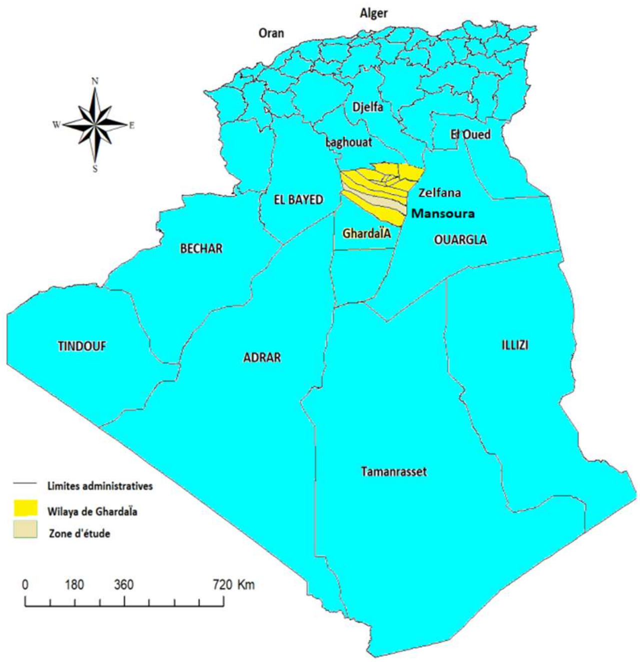

Figure 1: Location of the study area.

Soil sampling

The soil samples were done from 50 points which were georeferenced by GPS (UTM coordinate, WGS84) (Figure 2), a description of the environment was made, based on visual recognition of vegetation, nature of the rock and land use and the soil sampling was done from the ground at a depth of 0-25 Cm. In the laboratory the samples were dried and sieved for the following physicochemical analyses. The pH was measured, for the 20 collected samples, using a pH meter (Hanna Instruments, The Netherlands) in soil and in distilled water suspension with the ratio (2:5) (w/v) at 20 °C. Finally, the sample mixture was stirred for 1 minute and calibrated (Baise and Girard 1995). The electrical conductivity (EC) was determined using the conductivity meter (Hanna Instrument, The Netherlands) with a suspension of soil and water with a ratio of 1:5 (w/v) (Rhoades 1996). Organic matter was analysed using the Walkley–Black method that uses the heat of dilution from the addition of sulfuric acid to a potassium dichromate solution to help oxidize the organic carbon (Nelson and Sommer 1982).

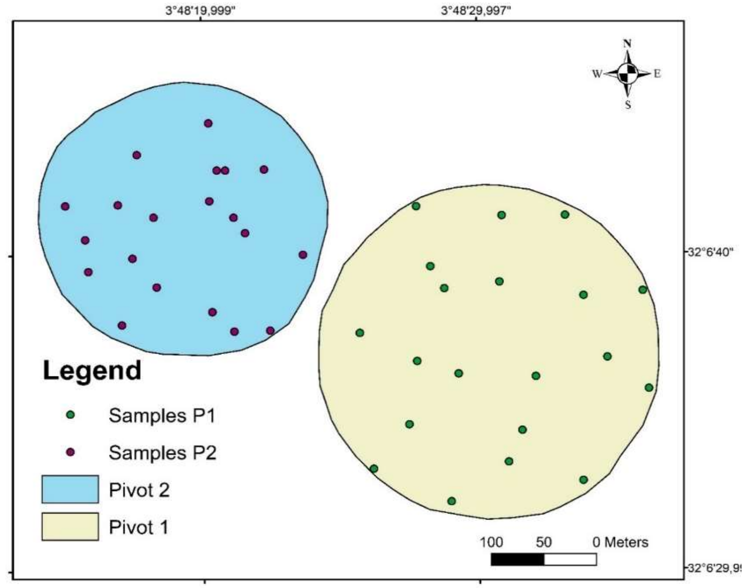

Figure 2: Position of soil samples in the pivots.

Statistical Analysis

Standard statistical analysis was performed, including the mean, minimum (min) and maximum (max) values, median, variance, standard deviation (SD), coefficient of variation (CV%), kurtosis and skewness of each parameter. For this preliminary analysis, the normality of the data was assessed before using geostatistics in order to obtain the prediction maps. The normality of each dataset was cheeked by tests (QQ plot) to ensure a normal distribution.

Predictive mapping

The IDW geostatistical technique was used to determine the spatial variability of reaction (soil pH), salinity (electrical conductivity) and soil fertility (organic matter).

Inverse Distance Weighting interpolation

Inverse Distance Weighting (IDW) interpolation is a spatial prediction technique commonly used in the geosciences (Shepard 1968). This tool assigns each input point a local influence that decreases with distance and calculates prediction values for an unknown interpolated point by weighting the middle of the known data point values. This method can be used if enough sample points have a distribution that occupies the area locally. It weights the points closest to the prediction point against those further away. IDW is an exact, convex interpolation method that only fits the continuous pattern of spatial variation.

A general form of predicting an interpolated value Z at a given point x based on samples Zi = Z (x i) for i = 1, 2,..., n, using IDW is an interpolation function:

$$Z(x) = \sum_{i=1}^{n} \frac{\omega_i(x) z_i}{\sum_{j=1}^{n} \omega_j(x)} \qquad \omega_i(x) = \frac{1}{d(x, x_i)^{\alpha}}$$

As defined by Shepard (1968), the equation presented above refers to a simple IDW weighting function, where x represents the predefined location of an unknown interpolated point, xi is the known data point, d is the distance from xi to x, n refers to the number of points used in the interpolation and p resembles an arbitrary positive real number known as the distance-decay or power parameter (normally α = 2 in standard IDW). IS important to note that in standard IDW, the parameter α is a specified user-defined constant value for all unknown interpolated points (Mei et al. 2015). The chosen interpolation technique is commonly used for this type of study and is the most common dispersion point interpolation method. It is based on the fundamental assumption that the interpolation surface should be influenced most by nearby points and least by distant points. The interpolation surface is a weighted average of the scattering points, and the weight assigned to each scattering point decreases as the distance between the interpolation point and the scattering point increases. In fact, the values at the unknown points are calculated as a weighted average of the values available at the known points (Yaserbi et al. 2009; Zimmerman et al. 1999). All data processing and analysis was carried out using QGIS 3.4 © software and statistical processing was carried out using Microsoft Excel ©.

RESULTS AND DISCUSSION

Soil analyses

Soil pH is an approximate indicator of nutrient availability in the soil (Nuraini et al. 2014). Therefore, it is important to measure this parameter. The study of the variability of the soil reaction, by determining the pH is carried out at a depth of 0 to 25 cm in all the plots studied with a number of 20 samples per plot. The results of soil pH analyses in the plots studied are summarised in Table 1.

Table 1. PH values of the two plots of the soil (P1& P2): values expressed as M± SD and n =20.

pH	**P1**	**P2**
Mean	8.4 ± 0.11	8.32± 0.17
Minimum	8.18	8.07
Maximum	8.64	8.64
Number of samples	20	20

In plot P1, the pH ranged from 8.1 (alkaline) to 8.64 (very alkaline) with an average of 8.4 ± 0.11. In plot P2, the pH ranged from 8.07 (alkaline) to 8.64 (very alkaline) with an average of 8.32 ± 0.17.

The results of soil pH analyses at the Mansoura station show that the soil is slightly alkaline, with mean pH values of 8.40±0.28 in pivot 1 and 8.32±0.29 in pivot P2. In regions with an arid or semi-arid climate, soils often have an alkaline character, due either to the use of irrigation water with a high pH, often rich in mineral salts (such as calcium or magnesium), which can lead to an increase in soil pH over time, or to the rapid evaporation of irrigation water, which leaves behind basic salts such as carbonates and bicarbonates, increasing soil pH. (Daoud and Halitim 1994; Djili et al. 2003).

Despite the highly significant decrease in pH, the soil remains very alkaline on average, perhaps due to the presence of limestone in the soil. Other causes may contribute to the decrease in pH in the study site, namely the use of fertilisers, especially urea 46%, which has an acidifying effect on the soil (Moughli 2000).

Geostatistical modelling of pH variability in plot P1 and P2

The IDW interpolation method was used to perform a spatial interpolation for the unsampled points, in order to obtain the soil response distribution model in the two plots (P1; P2). The results of IDW were presented in table 2. These results, expressed by the values of ME and RMSE were important (the values were close to zero for ME and close to 1 for RMSE) (Arslan 2012; Sun et al. 2009), This may explain the good accuracy of the IDW interpolation method.

Table 2. ME and RMSE obtained for IDW interpolation.

pH	**Pivot 1**	**Pivot 2**
ME	0.03	-0.02
RMSE	0.11	0.16

The maps drawn up (figure 3) show that all the soils have an alkaline pH, but a high level is noted in the centre of pivot 1, while in the pivot this accumulation trend was noted on the periphery of pivot 2.

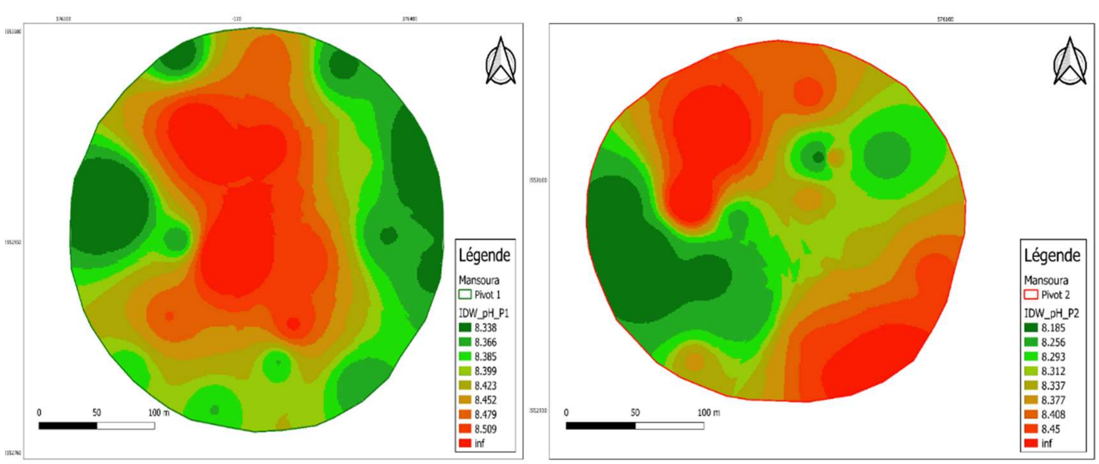

Figure 3: Soil pH distribution maps using inverse distance weighting (IDW) in the two pivots.

Intensive farming practices, particularly the use of potassium-rich fertilisers (such as potassium carbonate) for crops, can be rich in bases, which contributes to making the soil more alkaline. Soil exploitation caused a slight increase in the intensity of spatial variability of soil reaction in the two pivots.

Soil salinity

The results of soil electrical conductivity analyses in the plots studied are summarised in Table 3. In plot P1, the EC ranged from 0.75 (dS/m) (not saline) to 2.76 (dS/m) (saline) with an average of 1.52 ± 0.59. In plot P2, the EC ranged from 1.17 (dS/m) (saline) to 4.19 (dS/m) (very saline) with an average of 2.03 ± 0.67.

Table 3. Average values and statistics for soil conductivity.

EC (dS/m)	**P1**	**P2**
Mean	1.52±0.59	2.03±0.67
Minimum	0.75	1.17
Maximum	2.76	4.19
Number of samples	20	20

Geostatistical modelling of salinity variability in plots P1 and P2

The IDW interpolation method was used to perform a spatial interpolation for the unsampled points, in order to obtain the soil response distribution model in the two plots (P1; P2).

Table 4. ME and RMSE obtained for IDW interpolation

EC (dS/m)	**Pivot 1**	**Pivot 2**
ME	-0.02	0.02
RMSE	0.59	0.72

A soil salinity map is needed to assess and monitor salt accumulation. This information can be used as an effective tool to help farmers manage soil salinity problems affecting the agroecosystem. Moreover, the simplicity of this approach, together with its satisfactory accuracy, can greatly contribute to the prediction and mapping of soil salinity (Fourati et al. 2017; Mulla and Mc Bratney 2000). In this way, farmers will have information to detect saline soils and improve their management during the next cropping season (Benslama et al. 2020).

According to the maps of the spatial variability of soil salinity using IDW (Figure 4), an accumulation of salts to the east and west of pivot 1, while in pivot 2, a strong accumulation was noted in the centre and north of the study area.

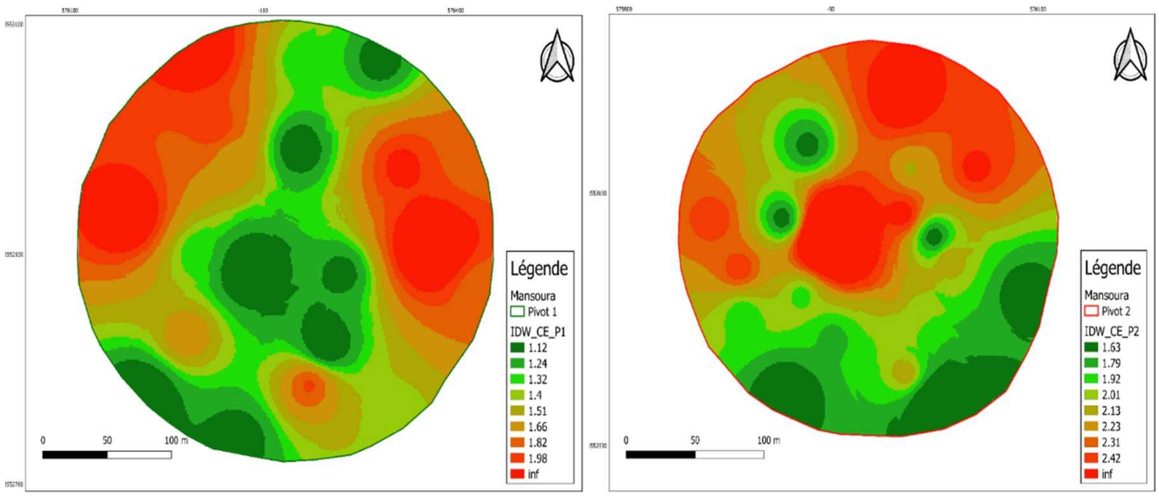

Figure 4. Soil salinity distribution maps using inverse distance weighting (IDW) in the two pivots.

Soil fertility levels

To increase food security and environmental sustainability in these farming systems, it is essential to adopt an integrated approach to soil fertility management that maximises crop production while minimising the depletion of nutrient reserves that can lead to land degradation. The results of organic matters analyses, in the studied plots are presented in Table 5. In plot P1, OM ranged from 0.02 to 0.96 (low OM) with an average of 0.33 ± 0.22. In plot P2, OM ranged from 0.07 to 0.4 (low OM) with an average of 0.23 ± 0.11.

Table 5. Average values and statistics for soil organic matter.

OM (%)	P1	P2
Mean	0.33±0.22	0.23±0.11
Minimum	0.02	0.07
Maximum	0.96	0.4
Number of samples	20	20

Geostatistical modelling of soil fertility variability in plots P1 and P2

The IDW interpolation method was used to perform a spatial interpolation for the unsampled points, in order to obtain the soil response distribution model in the two plots (P1; P2)

(Table 6). Organic matter (OM) is the backbone of soil fertility, and preserving it is essential for high-performance, sustainable agriculture. Soil organic matter is made up of several fractions that are more or less degraded and plays a key role as an essential regulator of soil properties, influencing many environmental factors that have a direct impact on crop productivity, particularly in non-fertile and weathered soils (Schulze et al. 2009).

Table 6. ME and RMSE obtained for IDW interpolation.

OM%	Pivot 1	Pivot 2
ME	0.03	-0.003
RMSE	0.25	0.12

According to the maps of the spatial distribution of organic matter using IDW interpolation, in the first pivot a strong accumulation trend was observed in the north-west and south-east of the pivot, while a weak accumulation trend was noticed in the south-west and east of the pivot (Figure 5). Concerning the second pivot, a strong accumulation rate was observed in the North-East, while a weak accumulation in the South and West of the pivot.

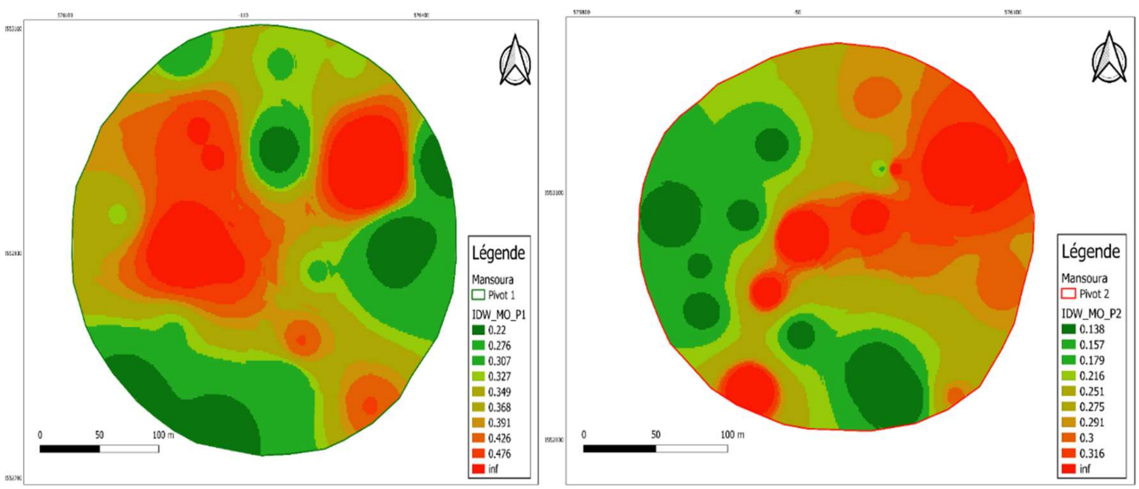

Figure 5. Maps of soil organic matter distribution using inverse distance weighting (IDW) in the two pivots.

Soil properties, which are intrinsically linked to OM accumulation, change rapidly when OM is incorporated or removed, whereas properties linked to weathering generally take longer to change (González-Pérez et al. 2004). Consequently, a study of the spatial variability of organic matter, integrating its different components, is necessary to better understand the major trends in this variability and the implications for soil management. In the two pivots studied, the soil showed an evolution from low to average fertility, a situation that reflects inadequate agricultural management overall. These results highlight the importance of sustainable management strategies focused on preserving and improving organic matter in order to optimise the productivity and resilience of agricultural soils.

Dry soils, which have a limited biological activity, are less able to retain matter than wet soils, which have high decomposition rates (Chenchouni and Neffar 2022). In addition, wind erosion washes away the soil layer containing nutrients, reducing the soil's capacity to retain nutrients (Lyles 1975). Finally, pH results show that our soil is alkaline, which hinders the availability of nutrients such as iron, manganese, copper and zinc, thus limiting fertility and plant development (Fernández-Cirelli et al. 2009).

CONCLUSION

The aim of this research is to evaluate the quality of different soil parameters under pivots (agricultural land) in the Ghardaïa 'Mansoura' region, in order to better understand their spatial variability at the pivot scale. The results of soil reaction, electrical conductivity and organic matter were geostatistically processed and interpolated by IDW, which is an uncomplicated, easy exact and convex interpolation that uniquely fits the continuous pattern of spatial variation. It is important to understand the spatial distribution of different soil parameters, in order to make better decisions for managing the system, in order to obtain a better quantitative and qualitative yield, i.e. to innovate a suitable strategy to ensure good, efficient and sustainable management capable of maintaining maximum crop yields for future generations. In recent years, remote sensing, GIS and modelling have become the preferred and inexpensive technological tools for mapping soil properties due to the vast areas covered, which is of the utmost importance from an agricultural and environmental point of view. This opens up great prospects for the future use of this technique on a large scale for sustainable soil management.

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