Sensors & Transducers, Vol. 237, Issue 9-10, September-October 2019, pp. 159-164

Sensors & Transducers

Published by IFSA Publishing, S. L., 2019
http://www.sensorsportal.com

New Approach to Optimization of Crop Production and Environment Protection

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Received: 30 August 2019 /Accepted: 27 September 2019 /Published: 30 November 2019

Abstract: It is well known that soil preparation plays a key role for optimization of the crop. It is less known that some fertilizer reach a plant root system below 20 cm after two or more years if applied at the soil surface. Also a large portion of the fertilizer never reaches the plant roots. As a consequence the large amount of the fertilizer is lost due to over dosage is used. In addition the excess fertilizer merges into undesired environment like ground water, plant leaves etc. and is spread by flies, bees and other bugs and finally end up in animal nutrients or human food. The solution to the problem is to provide the fertilizer under the ground level close to the plant root system, with the right composition of the nutrients and with the right quantity. In the paper we are presenting an agricultural machine capable to penetrate underground about 30 cm with vibrating tools and with the automatic dosage of different required fertilizers. The remaining problem is how to analyze the soil on the fly to determine which nutrients are missing and how much is needed to fulfill the optimal calculated fertilization plan. In the paper the soil characterization methods are briefly discussed and the results of the proposed soil electrical impedance frequency specter are presented and discussed [1].

Keywords: Soil classification, Soil impedance spectroscopy, Real-time soil sensor.

1. Introduction

Soil analysis is an essential problem that plays an important role in a nowadays agriculture. Literature indicates a common use of optical and impedance methods for soil quantitative and qualitative analysis, that may be used to design low-cost portable sensors for real-time application, i.e. on-the go soil sensors [2]. Therefore, a number of strategies with different degrees of success have been proposed for the environmental effects and soil properties prediction in a field. This paper is addressing the problem of the soil pre-processing prior to the measurements, as it can be critical due to a large number of unknown parameters when using the soil impedance spectroscopy, being the most promising soil classification method on the spot.

The goal is to perform the spectral analysis of the soil sample within less than few seconds time that includes the soil sample preparation, measurement and classification.

Among the soil classification principles the chemical analysis is the most accurate, but it requires a long delay time to obtain the results from the certified laboratory, and is therefore unsuitable for the application on the field, however if offers valuable reference results.

Other methods addressed in the paper are Visual and Near InfaRared (VIS, NIR) optical spectroscopy, optical analysis of dried droplets of the liquid with a mixture of soil and water containing the soil. Both methods allow the soil classification but proved to be slower and less suitable for on the fly classification.

The soil impedance spectra do not show directly the contents of the nutrients, intelligent algorithms need to be applied to recognize the specific nutrient and its quantity.

The soil classificatory device will be assembled into agricultural tool called vibrational sub-soiler (Fig. 1).

Fig. 1. Vibrational sub-soiler INO Brezice.

The attachment to regular tractor, the sub-soiler is shown in Fig. 2. It has an innovative pneumatic system to deliver the fertilizer mixture under the soil surface.

Fig. 2. Detail of vibrational sub-soiler INO Brezice.

Vibrational 2-row sub-soiler with pneumatic fertilizer device is intended for subsoiling the ground and for underground fertilizing in vineyards and orchards. It performs the following tasks:

- Subsoiling the ground close to the root structure.
- Increasing the aeration, permitting the filtering of the water from the surface down through the ground profile and allowing the moisture to be stored for the use during dry periods.
- Fertilizing close to the root structure under the pressure 1 bar. In this way fertilizer (K, P, Mg) moves freely to the roots.

When fertilizing over the ground, only a low quantity is infiltrated into the ground and by the time fertilizer loses its nature.

2. Soil Classification Methods

2.1. Chemical

Chemical analysis is most commonly used method to classify the soil quality in terms of its fertility and its content of the fertilizers. Based on this analysis, the fertilization plan is created and applied. This method is most accurate and reliable, but it needs to be performed in the certificated laboratory. This means a long delay to receive the result and is not suitable for the immediate application on the field.

2.2 Optical

Visual (VIS) and Near Infra-Red NIR spectroscopy is a promising technology. An example of soil spectra is shown in Fig. 3 for different soil samples with different types of nutrition added. The spectra do offer a possibility to classify the soil, however the procedure is too slow and too sensitive for on the field and on the fly operation.

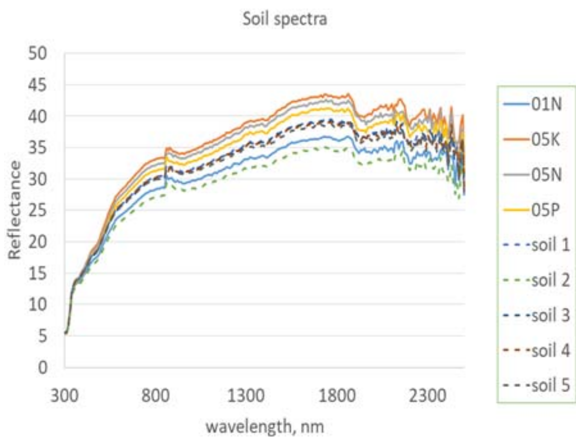

Fig. 3. Soils spectra of various soil types.

2.3. Droplets Analysis

Soil solution droplets analysis is one other possible way to classify the soil. An example of soil droplets of different soil samples with different concentration of fertilizers is shown in Fig. 4.

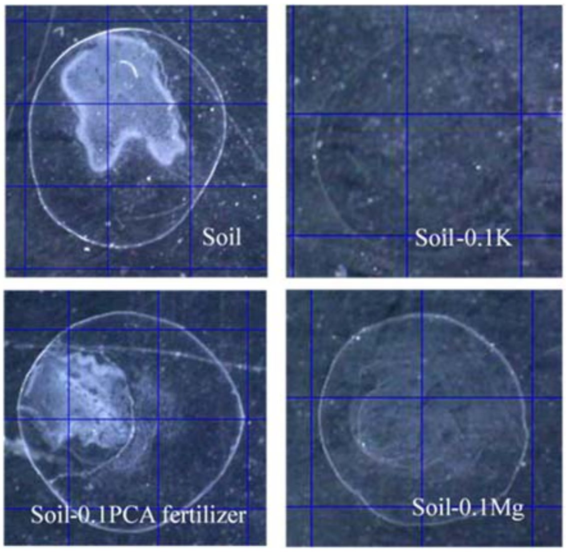

Fig. 4. Dried soil droplets and concentration with different types of the fertilizer.

As seen from Fig. 4 there is a clear distinction among different fertilizer added with low concentration. So it is possible to develop an algorithm for soil image characterization. Nevertheless the droplet preparation requires curing the droplet on the hot plate which is relatively slow and clumsy procedure. The procedure is shown on Fig. 5.

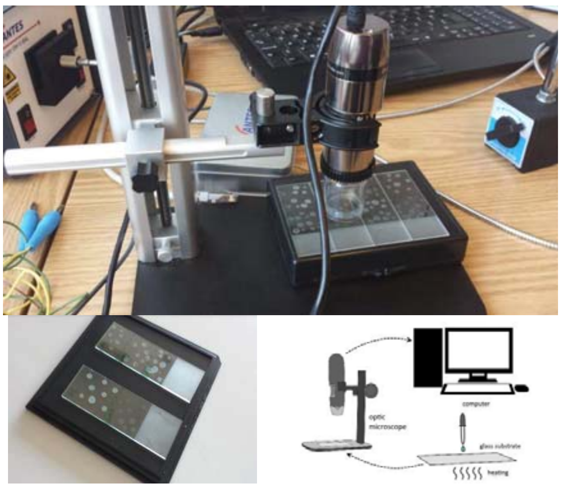

Fig. 5. Measurement set-up for soil droplet analysis.

3. Soil Impedance Spectra Analysis

A promising tool for soil analysis is soil impedance spectra. To measure soil impedance effectively a way to connect the measurement electrodes to obtain a repeatable result needed to be developed. The problem is causing the soil moisture, the soil granulation and the contents of sand and or other non-fertile foreign particles. Therefore it was decided to melt the soil in water and to remove non soluble parts of the soil by spinning.

The laboratory set up for soil impedance spectrometry acquisition is shown in Fig. 6.

Fig. 6. Soil impedance measurement set-up.

In Fig. 7 the measured soil spectra for the three soil samples is shown. For each measurement two measurements are shown to demonstrate a good repeatability. As shown in Fig. 7 soil 2TU and 3TU are poor soil in the lowest class (AAA) and soil 1TU is a good soil not requiring any fertilizer. The classes of the soil are as shown in Table 1.

Table. 1. Soil classes according to the amount of three most important fertilizers, Phosphorus, Potassium and Magnesium.

CLASS	Phosphorus mg/100 g	Potassium mg/100 g	Magnesium mg/100 g
A	0-10	0-10	0-10
B	11-20	11-20	11-20
C	21-30	21-30	21-30
D	31-40	31-40	31-40
E	>40	>40	>40

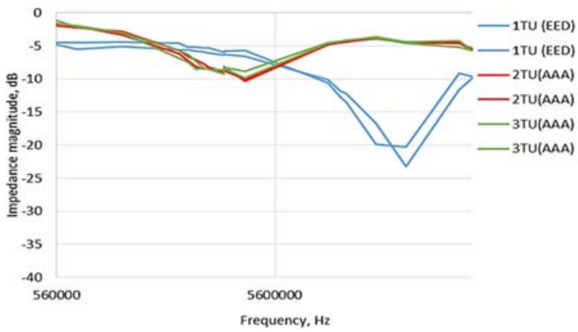

Fig. 7. Soil impedance spectra for soil 1TU, 2TU and 3TU together to its classification result.

4. Soil Preparation

For a successful transfer the development method to agriculture practice the following key issues must be observed.

- The information to the subsoiled must be delivered not later than 3 seconds due to the cultivation speed of the machine and due to effective and on time fertilizer spraying. The farmers know well that the soil quality is not evenly distributed on the field and just sampling the soil several meters apart is not sufficient. The requirement is to measure the soil virtually continuously.

- The procedure must run aromatically. Robotic operation is therefore mandatory.

- The fertilization plan needs to follow intelligent processing the collected data together with GPS position data to be further analyzed for enriching the database for a self-learning algorithm.

- The system must be robust and reliable to operate in harsh environment.

Collected soil has different moisture level and is therefore difficult to handle, but drying the soil requires additional time consuming step.

Fig. 8 shows the sample of the soil collected from the field and dried soil.

Fig. 8. Sample of typical soil collected from the field and dried soil.

Soil impedance spectra differ with moisture percentage. Fig. 9 show the measurement result when using dry soil and 15 % moisture soil.

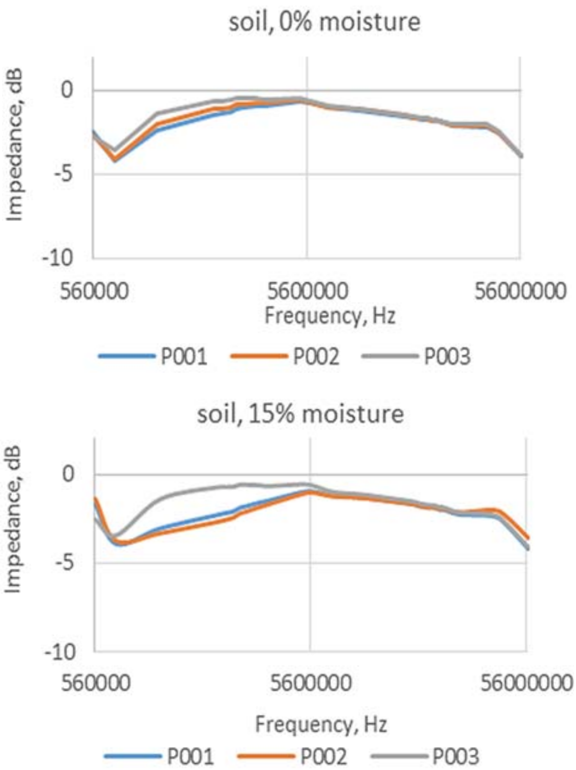

Fig. 9. Soil impedance variation due to moisture contents.

As can be seen from the figure there is no enough features to perform the classification.

Fig. 10 shows the resulting impedance specter when the moisture of 30 % has been added. As it can be seen the result is very similar to the reference soil. This spectra has been correctly characterized.

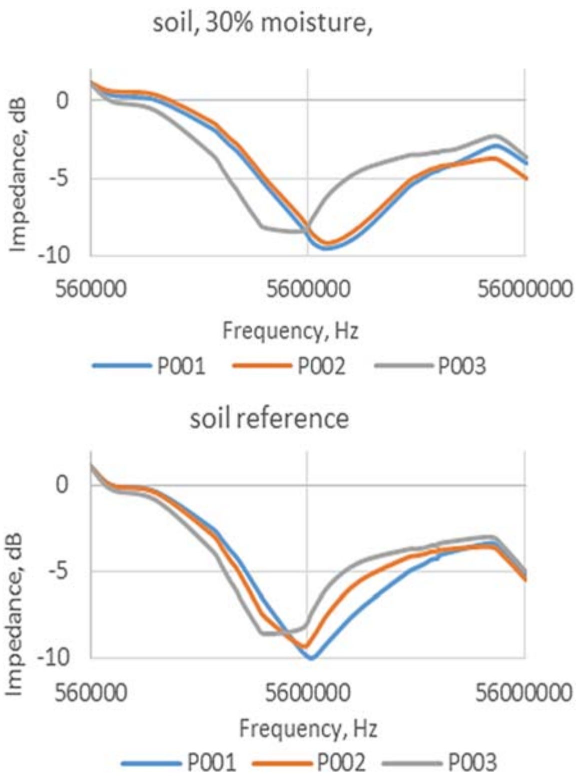

Fig. 10. Soil with moisture 30 % compared to reference soil.

In the following the soil preparation manual procedure is shown:

- Collect the sample of the reasonably dry soil Fig. 11.

- Add DI water approx. 60 % of soil volume Fig. 12.

- Stir to dissolve the soil (5 sec) Fig. 13.

- Separate the liquid part of the mixture by the centrifuge (5 sec) Fig. 14.

- Measure the impedance spectra (1 sec).

Fig. 11. Soil collection.

Fig. 12. Adding DI water.

Fig. 13. Stir to dissolve the soil.

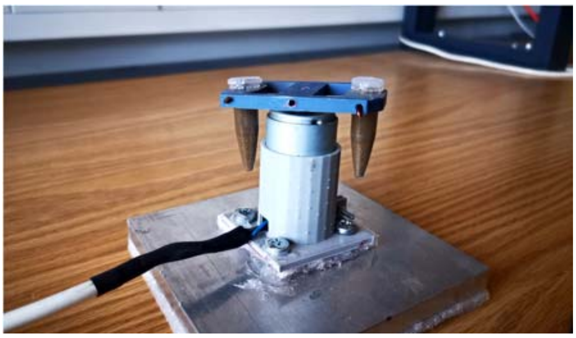

Fig. 14. Separate the liquid from the mixture by centrifugation.

The measured soil impedance spectra is shown in Fig. 15. It consists of the real and imaginary part and is presented as the magnitude and the phase of the impedance. The graph presents the most interesting part in frequency region between 14 kHz and 14 MHz where most of the characteristic features can be identified. The impedance pattern is compared to a database collected on over 200 sites in all geographic area of Slovenia. The database presents the reference soils impedance pattern classified with chemical on the basis of the principle of regression [3] analysis. The smart algorithm was developed to accurate classify any soil sample with an excellent degree of accuracy. A typical results of classification result for nutrition Magnesium, Phosphorus and Potassium are shown in Table 2.

The algorithm is self-learning by updating the data base. The larger data database the better classification accuracy is expected.

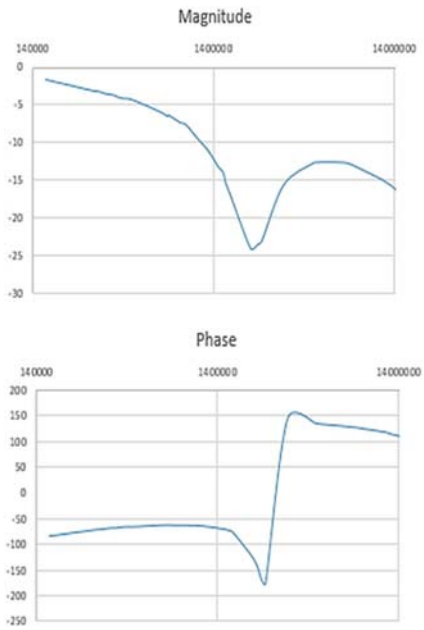

Fig. 15. Soil impedance spectra with shown magnitude and phase.

Table 2. Classification results from smart classification algorithm.

Mg –		
Correctly Classified Instances	2303	99.4816 %
Incorrectly Classified Instances	12	0.5184 %
Kappa statistic	0.9922	
Mean absolute error	0.0021	
Root mean squared error	0.0367	
Relative absolute error		0.7793 %
Total Number of Instances	2315	
P_2O_5 –		
Correctly Classified Instances	2304	99.5248 %
Incorrectly Classified Instances	11	0.4752 %
Kappa statistic	0.9936	
Mean absolute error	0.0022	
Root mean squared error	0.0375	
Relative absolute error		0.7468 %
Total Number of Instances	2315	
K_2O –		
Correctly Classified Instances	2305	99.568 %
Incorrectly Classified Instances	10	0.432 %
Kappa statistic	0.9942	
Mean absolute error	0.0025	
Root mean squared error	0.038	
Relative absolute error		0.8392 %
Total Number of Instances	2315	

5. Conclusions

The presented results prove the concept. Even by using manual soil preparation. The total time to provide classification result is as short as 11 seconds.

It is reasonably to believe that the robot can shorten the time to the requested 3 seconds. The solution presented is affordable and can be multiplied to provide. A parallel operation and therefore scan the soil with dense grid tom fertilize the soil more evenly and to expect an even crop over all treated area. The cost of fertilizer is dramatically reduced and the negative impact of farming to environment is minimized.

Acknowledgements

The authors would like to thank the Slovenian Research Agency to cofound the research.

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