Automated mobile field laboratory for on-the-go soil-nutrient analysis with the ISFET multi-sensor module

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Abstract

With the mobile field laboratory soil2data soil sampling and soil nutrient analysis at the same time can be carried out directly on the field. Besides the advantages of a fast data availability of the soil nutrient contents and the omission of soil material transport to the laboratory, it forms a future basis for new application options, e.g. a verification of the current analysis results with existing results and if necessary repetition of the soil testing during the work on the field or a high sampling density. The developed process flow is fully automatic. The measurement results are immediately available and can be stored on external data platforms for analysis and further use. An innovative key component is the custom-specific ISFET multi sensor module. It measures values for the ions NO_3^-, $H_2PO_4^-$ and K^+, the pH and electrical conductivity of the soil extraction solution. The ISFET multi sensor module is specially developed for soil nutrient analysis. The phosphorus measurement was further developed for the project "soil2data". The mobile field laboratory can be used with various vehicles.

Introduction

Small-scale knowledge and spatial distribution of the soil nutrient content in combination with further information (e.g. soil texture, yield level) is an important basis for site-specific crop production for demand-oriented fertilisation in plant production. An agricultural field is not a homogeneous unit. Within a field, geological or pedogenic differences are often noticeable (e.g. soil texture, soil type) [1] and the yield varies [e.g. 2]. It is often observable that the yield level also varies with the variations in soil conditions [e.g. 3]. For effective, site-specific crop production, this detailed information is of fundamental importance for the specific sub-field,

such as yield, soil texture and/or soil nutrient status. Soil sampling is used to determine the nutrient status on arable land or on sub-fields. Among other things, the current soil nutrient status has an important influence on the yield [4, 5, 6]. In the case of site-specific fertilisation, the fertiliser application is adjusted to the site-specific yield and to the current soil nutrient status of that specific sub-field [e.g. 7]. The soil nutrient status can show significant variability within an agricultural field due to different nutrient uptake by plants and different soil textures [3]. Knowledge of the current, small-scale distribution of soil nutrients is an important information for economically and ecologically sustainable plant production [e.g. 4, 2].

A combined soil sampling and soil analysis on the field with a mobile field laboratory creates the conditions for a very fast delivery (< 1 day) of the soil nutrient status. The associated digitalisation of the process allows these analysis values to be automatically made available for other processes (e.g. fertiliser quantity calculation) and the data processing speed to be further increased. This makes it possible to do soil sampling and analysis directly before fertilisation and to optimise fertilisation – on the basis of the current soil nutrient status – for a needs-based fertilisation. The soil samples have no longer to be transported to a laboratory, which saves transport costs and time. There are no more "disposal costs" for the remaining soil material at the laboratory site. Further additional options such as the verification of the collected analysis results with available soil nutrient analysis values from previous measurements and, if necessary, an immediate repetition of the measurement in the event of inexplicable deviations would be possible. Or the compilation of time series over several years or within a vegetation period is conceivable. [8]

Concept mobile field laboratory "soil2data"

The interdisciplinary research project "soil2data" is developing a mobile field laboratory for on-the-go soil nutrient analysis (see Fig. 1). The process steps such as soil sampling, soil sample preparation and soil sample analysis for a mobile field laboratory are modified, adapted and automated (see Fig. 2). The mobile field laboratory soil2data combines the processing sequences "soil sampling" with "soil preparation" and "soil analysis". The individual processes so far become part of the overall "soil2data" process. The process steps operate parallel. The design of the system is modular. Three platforms are available as carrier vehicles. The overall soil2data process can be divided into 3 sub-processes:

1. planning the soil sampling (e.g. field selection, generate sampling line) before the actual field work
2. soil sampling, preparation and analysis directly on the field and
3. data management and post-sampling documentation. [8]

Fig. 1: „soil2data mobile field-lab“ integrated into the field robot BoniRob (left site) and on a commercial carrier platform (right site)

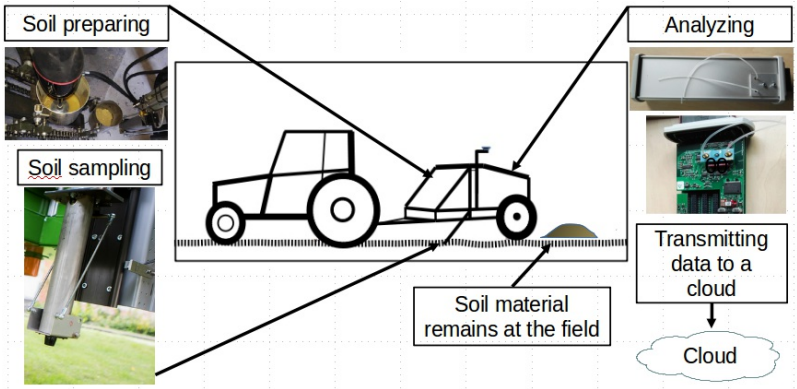

Fig. 2: Sketched illustration of the mobile field-lab and the process steps on the field

Sub-process 2 includes the sub-modules "soil collection", "soil preparation" and the ISFET multi-sensor module. The following components are combined in this subprocess:

- soil sampler for collecting soil sample material
- collecting container with transport device for collecting and preparing a mixed sample
- measuring unit for determining the collected soil volume
- linear actuator with mixer for physical preparation and homogenisation of the soil sample
- various pumps and valves with supply lines for the transport of extraction agents and soil extraction
- filter station for filtering soil extraction with transport system
- cleaning system for the cleaning of individual components and
- Industrial PC system with real-time Ethernet bus for controlling the components and communicating with the readout circuit of the ISFET multi sensor module and also the carrier platform. [9]

In order to reach a high level of comparability and correlation between the analysis results of the mobile field laboratory and the usual standard laboratory analysis, the scope and quality of soil sample preparation in the soil2data process is an important and fundamental process step. If the field results are highly correlated with the laboratory results of the standard test, the LUFA fertiliser recommendations can be used to evaluate the soil nutrient content. The systematic approach for soil preparation and the extraction agents used are of high relevance for the generation of comparable analysis results. Soil preparation can be done in two stages with different extraction agents. For the basic setting, the mixing ratios of extraction agent to soil or the physical preparation time can be modified. In the research project "soil2data" the project partner LUFA Nord-West - an accredited service laboratory of the Chamber of Agriculture Lower Saxony / Germany - is developing a new soil preparation method for the mobile field laboratory [10] in order to achieve a high comparability of the field results with the laboratory results.

The soil2data soil preparation method developed is as follows (s. Fig. 3):

Stage 1: After determining the mass of soil material in the collection container, the first extraction liquid (extraction agent 1) is added and stirred vigorously with a mixer for a defined time. A defined quantity of soil extraction is then pumped off and pumped to the filter unit.

Stage 2: Adding a second extraction liquid (extraction agent 2) to the remaining soil extraction in the collecting tank. The soil extraction in the collecting tank is stirred vigorously again with the mixer. A defined quantity of soil extraction is then pumped off again and conveyed to the filter unit, Any residual material from the soil extractions remains on the field.

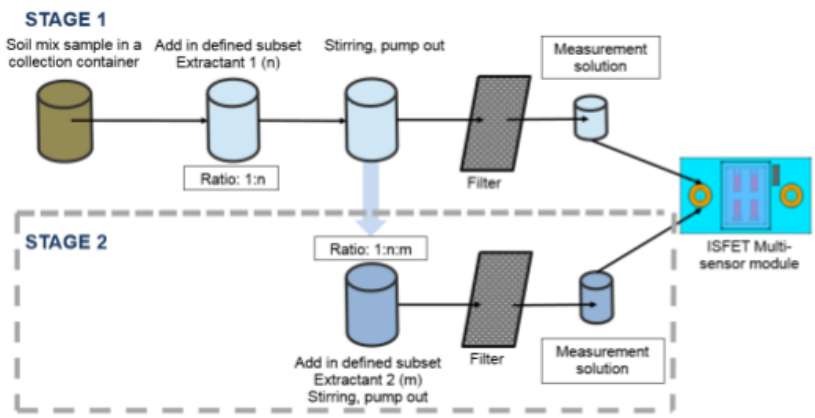

Fig. 3: "soil2data" soil preparation and nutrient extraction procedure

Key component "ISFET multi-sensor module"

An ISFET multi-sensor module (Lab on Chip) from Microsens is used to analyse the extracted soil samples (s. fig. 4). This "Lab on Chip" consists of 4 single ISFET sensors and

further components for the measurement of the nutrients nitrate (NO3-), potassium (K+) and dihydrogen phosphate (H2PO4-) as well as pH value, temperature and electrical conductivity of the extracted soil sample. The ISFET multi-sensor module has been specially developed for soil nutrient analysis and the phosphorus measurement has been further developed for the soil2data project. The control and readout electronics of the ISFET multi-sensor module have also been further developed, now stable measurements are possible with the ISFET multi-sensor module. [9]

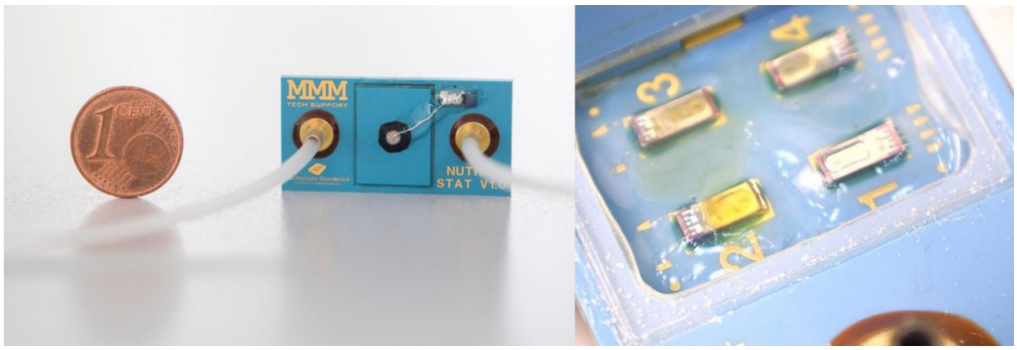

Fig 4: "soil2data" multi sensor module with four ISFET chips

Conclusion

The different process steps from collecting soil samples to soil sample preparation (e.g. handing over a mixed soil sample for preparation, extraction of nutrients with different extraction agents, filter processes, etc.) and analysis have been completed and tested. The newly developed two-stage soil sample preparation method allows simultaneous parallel execution of the necessary work steps so that the entire process sequence can be realized in non-stop mode. The mobile field laboratory "soil2data" enables the nutrient analysis for pH, K^+, NO_3^- and H_2PO_4- to be carried out directly on the field.

Acknowledgements

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