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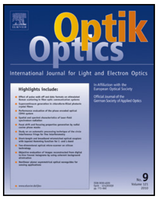

Design of portable near infrared soil nutrient measuring instrument

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ABSTRACT

The aim of the present work was to design a portable instrument to predict the constituents of total nitrogen and organic matter in soil. Data from recent reports as well as our experiments show that these constituents exhibit absorption peaks in the near-infrared region around 850 nm and 940 nm. We designed a portable instrument that adopted diffuse reflectance spectroscopy. Subsequently, we conducted instrument performance tests to obtain the curves relating the actual and calculated values. Experimental results showed that the coefficients of determination (R^2) for predicted total nitrogen and organic matter in oven-dried soil sample were 91.84% and 81.06%, respectively, and the corresponding values in wet samples were 90.17% and 80.24%. For soil organic matter and total nitrogen content in the samples, we found clear correlations between the actual values and calculated values.

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1. Introduction

Diffuse near-infrared reflectance spectroscopy is considered a promising approach for addressing soil quality, and its use directly in the field may be a surmountable challenge [1]. Conventional soil analysis in the laboratory is expensive, labor-intensive, and time-consuming. However, diffuse near-infrared reflectance spectroscopy, which has the advantages of requiring no preparation and being non-destructive, can improve effectiveness in terms of time and cost, and may be performed directly in the field [2].

Near-infrared spectroscopy (NIRS) is widely used in industrial sectors such as agriculture, tobacco, medicine and chemical [3]. With the maturation and development of NIRS, many scholars have attempted to use a universal near infrared-spectrum instrument to measure the soil total nitrogen content and organic matter content, and then achieved satisfactory results by establishing a forecasting model. Bowers and Hanks Al-Abbas [4–7] found that in the near-infrared region, the characteristics were related to several functional groups of organic compounds. This discovery laid the theoretical foundation for detecting the contents of soil organic matter by means of NIRS. Many scholars including Wangner, Chodak [8], and Chang [9] have also used NIRS to forecast soil organic matter and total nitrogen content; in their studies values for the coefficient of determination R^2 were greater than 0.85, which showed that the chemical measurements and estimated values were in good agreement [10–14].

In the present case, although predictions for the total contents of nitrogen and organic matter in soil by using an analytical spectral device have been relatively accurate, but the typical spectrophotometer still has the disadvantages of high cost and bulkiness. Consequently, commercially available spectrophotometers cannot be used to estimate total nitrogen and organic matter in soil in situ. To resolve this situation, we designed a practical portable detection device to meet the urgent needs for assessing soil fertility.

In previous studies, we have determined that several absorption peak clearly correspond to several organic substances and total nitrogen in the near infrared-spectrum region, using a general instrument. Here we adopted an optical filter to obtain the narrow-band near-infrared light, which we need separately to predict the contents of organic matter and total nitrogen.

2. Experimental details

2.1. Materials and methods

The soil samples originated from a relatively loamy farmer's field in Harbin, Heilongjiang province: 45°42′35.68″ N, 126°34′51.55″ E. The grid sampling method was used to collect the soil samples, and the sampling field was divided into 10 sites of size 1 m^2, at 5-m intervals. The sites were rather evenly distributed over the fields. In each site, 5 samples were collected (one in the center and four in each corner) at depths in the range of 15–20 cm. A total of 50 soil samples were divided into two groups, A and B. Group A samples

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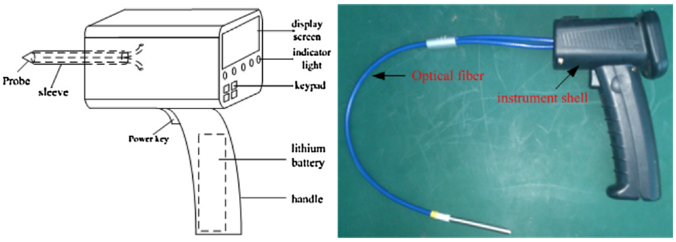

Fig. 1. Block diagram and photoghaph showing instrument structure.

were taken back to the chemical laboratory in Harbin University of Science and Technology for chemical analysis to measure the total nitrogen and organic matter contents. Group B samples were kept to predict these measures by using the designed instrument.

All the collected samples were air-dried at room temperature for one week then oven dried at 40 °C for one night, and then gently crushed to a sieve of 2-mm. The chemical methods used to measure the contents of organic matter and total nitrogen were the resistance furnace and Kjeldahl methods, respectively.

2.2. *Design of overall scheme*

The overall size of the instrument must meet the requirements of a portable device: this required that the hardware components be designed simply and easy to operate. The instrument was designed as follows. First, a narrow-band near-infrared light was transmitted to a depth of 30 cm beneath the ground surface by an optical fiber, which then collected the reflected light that was partially absorbed by the organic and total nitrogen and transmitted back to instrument. Although the photoelectric conversion was completed, the diffuse light intensity was correlated with the output voltage. The intensity of diffuse reflection light was determined by the absorption of the soil organic matter and total nitrogen; it was inversely proportional to the content of material. That is, the higher the content, the greater was the intensity absorbed and the lower was the diffuse light intensity.

The instrument comprised two parts: the optical part and the circuit part. Its overall structure is shown in Fig. 1.

2.3. *Design of optical structure*

The main function of the optical path was to provide the needed near-infrared light. We chose interference filters as the spectral components in the optical path structure. A block diagram of the optical structure principle is shown in Fig. 2. The optical path consisted of a near-infrared illuminant, optical filter pack, Y-type quartz optical fiber, and PbS detector. Near-infrared composite light was split into narrowband near-infrared light at specific wavelengths by the band-pass interference filter. In addition, the Y-type optical fiber has three probes: a light incident probe, light reflection probe, and soil contact portal. The incident probe received narrowband near-infrared light, which was split as mentioned above. The reflectance probe and detector were coupled together with a fiber interface. The function of the soil contact probe was to irradiate the near-infrared light into the soil and to collect the diffuse reflected light.

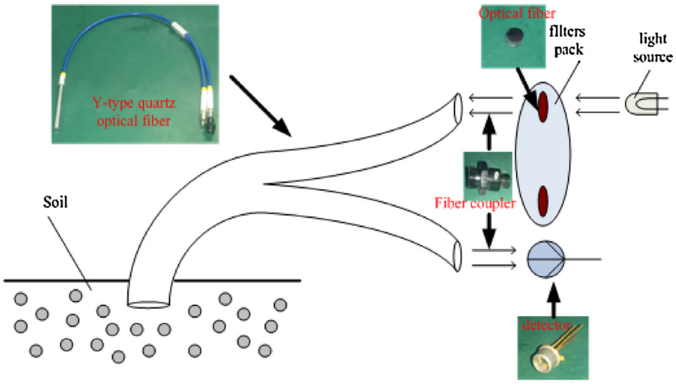

Fig. 2. Optical structure of the instrument.

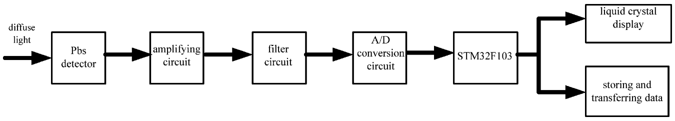

Fig. 3. Block diagram of electric circuit.

2.4. *Selection of design and type of each device in light path structure*

A bromine tungsten lamp was chosen as the instrument illuminant. The lamp was low in price; in addition, its spectral range was extremely wide and its volume was small. We chose a 12-V power supply bromine tungsten lamp (OSRAM, Germany). Two interference filters on the filter pack were used to separate the monochromatic light from the composite near-infrared light.

The filter pack, which was placed between the illuminant and the incident optical fiber probe, allowed us to obtain a near-infrared light of characteristic wavelength that could be directly irradiated at the incident optical fiber probe. The filter pack included two interference filters, one of wavelength 850 nm and the other of 940 nm.

We chose a PbS detector (CALSENSORS Co.) of the photoconductive sensor type: when it was illuminated by near-infrared light whose the wavelength was in the range of 800–2500 nm, the conductivity would be increasing.

2.5. *Design of circuit system*

The electric circuit part included an amplifying circuit, low-pass filter circuit, A/D conversion circuit, display, storage circuit, and data transmission circuit. A diagram of the electric circuit is shown in Fig. 3.

Diffuse light illuminated the detector through the optical fiber and the photoelectric conversion transformed light signal to electrical signal. The power supply provided a stable bias voltage for the detector, whose output voltage changed as a function of the light intensity. Subsequently, the AD620 instrumentation amplifier amplified the change in the sensor voltage. A low-pass filter was used to filter the high-frequency interference after amplification. A single chip microcomputer (STM32F103) was used to complete the computing of numerical absorbance, liquid crystal display data, data transmission and storage.

2.6. *Design of instrument software*

The field-measuring conditions require that the measured results be displayed at the same time a single measurement is performed. Therefore, the instrument software mainly followed the design of mcu program, which included signal A/D conversion, filter selection, signal processing, data display, transmission and storage.

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