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Full Length Research Paper

Development of a portable plant nutrition test instrument based on spectroscopic technique

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A portable plant nutrition test instrument with global positioning system (GPS) module was designed for the fast and noninvasive measurement of the field crop nutrition content and distribution. Two Light Emitting Diode (LED) light resources at 650 and 940 nm were used to obtain the transmittance spectra of leaves. The chlorophyll content prediction model was established according to the relationship between transmission spectra and SPAD value. The nitrogen content prediction model was established according to the relationship between transmission spectra and the nitrogen contents obtained by combustion method. The water content prediction model was established according to the relationship between transmission spectra and the water contents obtained by weight method. The results indicated that correlation coefficients (R^2) for chlorophyll content, nitrogen content and water content were 0.92, 0.91, and 0.76, respectively. With GPS module, the portable instrument can support the nutrition and position information of the sampling points to the GIS software in the management computer to do the nutrition distribution analysis. The portable instrument is helpful to provide a high efficient and scientific way for the management and operation in precision agriculture.

Key words: Spectroscopy, chlorophyll content, nitrogen content, water content, global positioning system (GPS).

INTRODUCTION

Chlorophyll, nitrogen, and water are three main indexes for the plant nutrition evaluation (Fasgola et al., 2002). They are important for the photosynthesis of plant, which allows plants to obtain energy from light. Chlorophyll is a green pigment, which absorbs light most strongly in the blue portion of the electromagnetic spectrum, followed by the red portion. Nitrogen is one of the key nutrition elements of plant (Raun et al., 2002). Water is necessary for the entire living organism. The contents of chlorophyll, nitrogen, and water in plants can reflect the growing condition of plants directly or indirectly. Therefore, it is very important to determine these indexes.

The plant nutrition detection becomes a key research field all over the world in recent years. Its research started from using chemical reagent methods, then spectrophotometry, *in vivo* chlorophyll meter, polarography, photoacoustic spectroscopy (Li et al., 2005), and colorimetry. Recently, the spectroscopy techniques were used, including, spectral detection (Galvão et al., 2008), spectral imaging detection (Chen et al., 2007; Feng et al., 2006; Xu et al., 2007), and especially plant’s canopy image and spectra scanning techniques (Scott et al., 2003; Feng et al., 2006). These techniques need to measure the chlorophyll content firstly, then deduce the nitrogen content based on the quantitative relationship between the chlorophyll content and nitrogen content (Zhu et al., 2006; Van den Berg and Perkins, 2004). The processes of these techniques are complex. The commercial products to determine the chlorophyll content are SPAD-502 (Minolata, Japan) and a chlorophyll fluorescence test instrument produced by

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an American company. Additionally, these instruments are very expensive. The instruments produced in China can only determine the chlorophyll content. The measurement parameter of these instruments is single. Moreover, it is important to determine the measurement positions of the sampling points. The instruments mentioned above cannot achieve this purpose. Therefore it is necessary to develop a plant nutrition test instrument which can determine the plant nutrition accurately, reliable, fast and non-invasively, and can be used for the large-scale digital management.

This paper designed a plant nutrition test instrument based on spectroscopy technique. The instrument can be used for the measurement of chlorophyll content, nitrogen content and water content of plant. It has the features of high accuracy and reliable ability, and can use the GPS technique to measure the position information of the sampling points, and then use the wireless data transport technique to send the nutrition information and the position information to the management computer. A large-scale field crop nutrition level distribution map can be drawn by GIS computer software based on the measured information. This instrument is helpful to improve the efficiency and accuracy of the large-scale field crop nutrition monitoring and management, and has a brighter application future.

MATERIALS AND METHODS

Sample preparation

Two hundred leaves as the sample were from the rice with different nitrogen level in Zhejiang Jiangshan National Rice Base were obtained. 150 samples were randomly selected as calibration set and the remaining 50 samples were used as validation set. The calibration set was applied for the development of calibration model, whereas the validation set was only applied for the performance evaluation and assessment. It should be noting that no single leaf sample was used both in calibration and validation sets at the same time.

The original AD data and predicted chlorophyll data were obtained by using the portable instrument. Then the nitrogen contents of these rice leaves were measured by Rapid N Cube. The quantitative models were established based on two plans, respectively. The chlorophyll content was measured by SPAD 502. The water content was measured by Physical weighing method.

Spectral acquisition and reference method for chlorophyll, Nitrogen and water content

The fresh leaf samples were used for spectral acquisition as soon as they were collected for the farm field. A handheld Vis/NIR Spectroradiometer called FieldSpec®HandHeld and HandHeld Pro FR (325–1075 nm)/ A110070 (ASD, USA) was applied for spectral scanning, the ASD is shown in Figure 1. The light source was a Lowell pro-lam interior light source assemble/128930 with Lowell pro-lam 14.5V Bulb/128690 tungsten halogen bulb which contain the visible and near-infrared region. The field-of-view (FOV) of the spectroradiometer is 25°. The leaf sample was placed directed in the center of field of view of the spectroradiometer. The spectroradiometer was placed at a height of approximately 100 mm and 45° angle away from the center of sample. The light source was placed at a height of approximately 250 mm 45° angle away from the sample. The reflectance spectra from 325 to 1075 nm were measured at 1.5 nm intervals and the average reading of each saved spectrum was 30 scans. The average spectrum of leaf sample was used in later analysis. All spectral data were stored in a computer and processed using the RS3 software for Windows (Analytical Spectral Devices, Boulder, USA) designed with a Graphical User Interface.

The reference method for nitrogen content detection was Dumas combustion method using Rapid N Cube (Elementar Analysensysteme, Hanau, Germany). After complete combustion, reduction, purification and detection, the nitrogen content of oilseed rape leaves was obtained through the Rapid N Software V 3.4.0 (Elementar Analysensysteme, Hunau, Germany).

System design

Optical path design

Two Light Emitting Diode (LED) lights are designed to light the leaf with the protection of the light block pads. Also with the protection of the light block pads, two photoelectric sensors are designed to measure the transmittance light of leaf from the LEDs. The measured light then is transformed into electric signal by the photoelectric sensors. The signal is recognized and calculated by MCU after conditioning transform. The optical path design schematic diagram is shown in Figure 2.

Hardware system design

Two LEDs can emit spectral light at 650 and 940 nm (Pandey and Gopal, 2011), respectively, and are used as the test light source. The electric signal measured by the photoelectric sensors is the transmittance spectra of leaves at the feature wavelengths. The signal is transformed by a Digital Analog Converter (AD) and then inputted into CPU for the data process and model calculation. Meanwhile the GPS signal is received every second by interrupts. The measured signal and the GPS positioning signal are written into FLASH and show at LCD screen. At the same time, these signals are sending to the management computer by using the wireless data transport model LEA-AP232. The hardware block diagram is shown in Figure 3. The instrument is shown in Figure 4.

Software system flowchart

The software system of the instrument is mainly programmed based on the modules, including the main program process control, signal denoising software, GPS signal reception and decoding, human-computer interaction, model operation, FLASH read and write, wireless data transmission program module and alarm program module. The software system flowchart is shown in Figure 5.

System model establishment

Chlorophyll content measurement model

The chlorophyll content measurement model was established based on the analysis of the original AD measured data of two sensors and the measured data by using SPAD-502. Because the color of chlorophyll is green and the chlorophyll content has the linear relationship to the spectra, the relationship between these two kinds of data was established based on numerous experiments. The specific experiment plan was: (1) to measure the spectra of

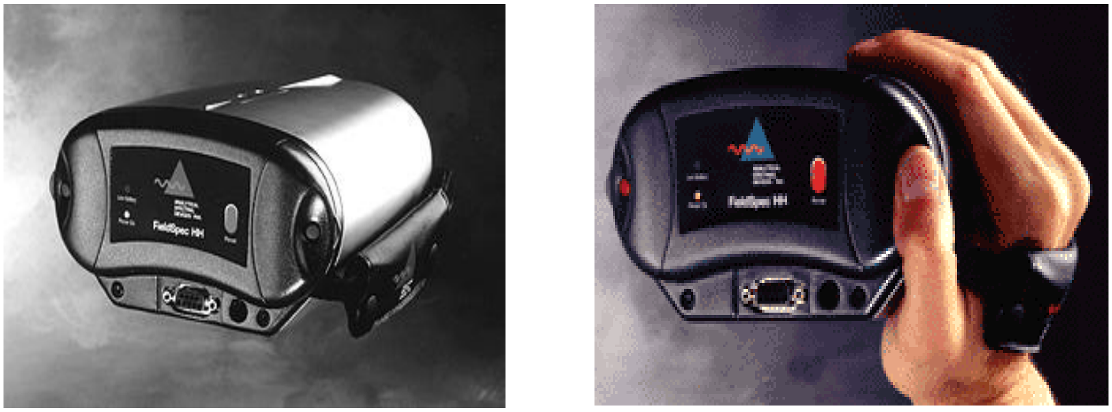

Figure 1. Handheld visible/near infrared spectrometer (ASD).

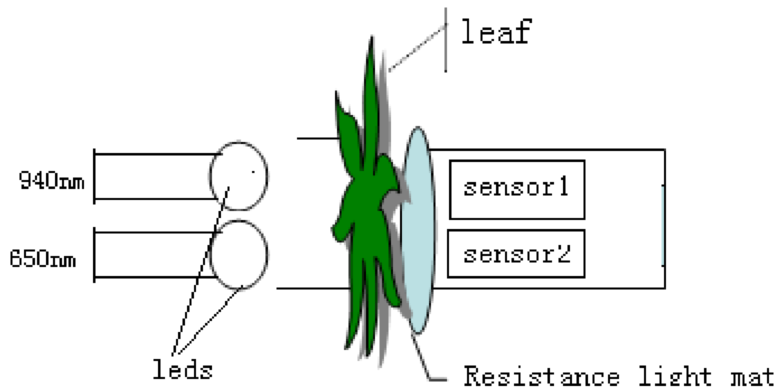

Figure 2. Optical path design schematic diagram.

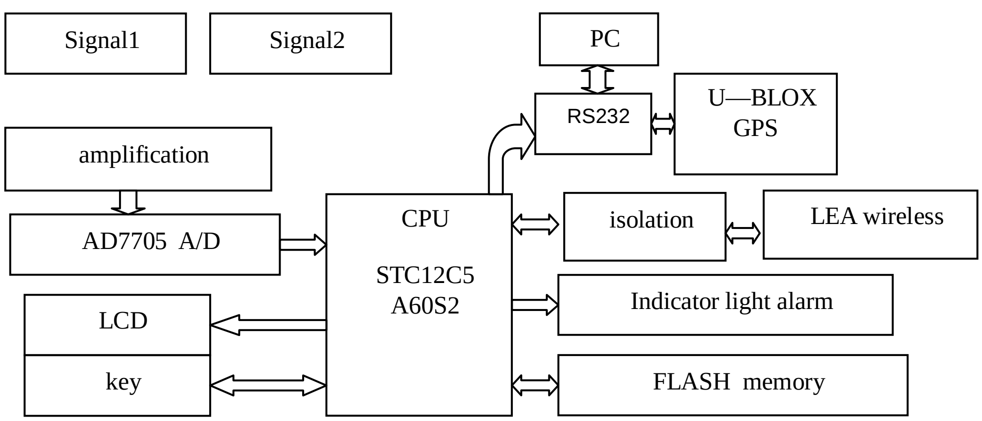

Figure 3. Hardware block diagram.

200 leaf samples with different SPAD values; (2) to measure the transmittance spectra of leaves at red light band and near infrared spectral band by using our test instrument, five times for each leaf, and the average data was used as the spectra for that leaf; (3) to obtain the linear relationship of AD signal and SPAD measured signal. The linear relationship plot is shown in Figure 6.

The determination coefficient (R^2) of this linear relationship was 0.914, showing that the established model is acceptable. In order to prove the reliability and stability of the model, we programmed the model into the software system and used 50 leaves with different

Figure 4. Instruments physical picture.

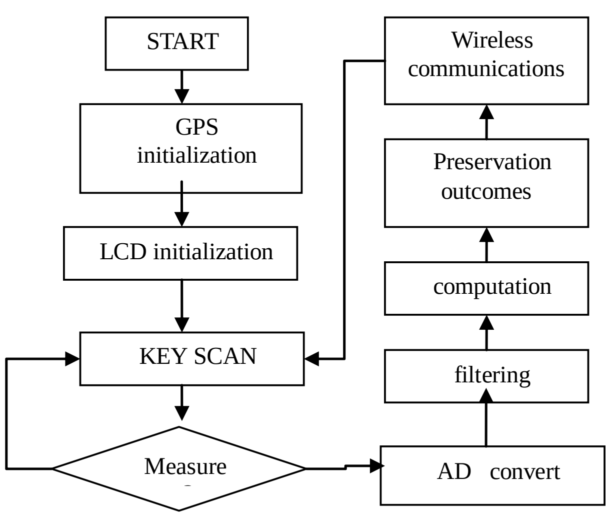

Figure 5. The scatter plots of validation set by direct linear function (Software system flowchart).

SPAD values as test samples. The relationship of the data predicted by the portable instrument and the SPAD measured data was established and is shown in Figure 7.

From Figure 7, it can be seen that a good correlation relationship was obtained. There is no large error, proving that the portable instrument has a good accuracy which is acceptable for the agriculture detection.

Nitrogen content measurement model

Nitrogen is sensitive to the red light and near infrared light, and nitrogen content has relationship with chlorophyll content. However the relationships between chlorophyll content and nitrogen content are different for different plants (Wang and Bai, 2005; Font et al., 2005). Therefore two experiment plans were used for the same plant species, in order to find the optimal data process model. Plan one, to establish the quantitative model based on the chlorophyll contents and the nitrogen contents which were measured based on Dumas combustion method by using Rapid N Cube (Elementar Analysensysteme); plan two, establish the quantitative relationship between nitrogen contents and the spectra measured by the portable instrument (Xue et al., 2003; Lu et al., 2007). The step linear regression was used to obtain the test model with more reliability and more accuracy.

The relationship of chlorophyll contents and nitrogen contents obtained in Plan one is shown in Figure 6. It was not satisfied, because of the low R^2 of only 0.7.

The stepwise linear regression was used to obtain the regression model in plan 2. The obtained function is shown as follow:

$$\hat{y}=9.68-0.32x_{650}-0.018x_{940} \qquad (1)$$

The quantitative relationship of predicted values and reference nitrogen contents is shown in Figure 9, showing that the relationship was satisfied because of a high R^2 of 0.92. Moreover, a knowledge database was used to overcome the disadvantage of the nitrogen measurement that the prediction models are different for different kinds of plants. The models established based on different kinds of plants were inputted into the knowledge database. When the portable instrument is used to measure the nitrogen content of a certain plant, it only needs to load the model of the according plant and to do the nitrogen measurement.

Water content measurement model

Because the near infrared spectra are sensitive to thewater content (Jiang and Huang, 2006; Zhang et al., 2007), the water content measurement analysis was also executed based on two plans. Plan one, one hundred of leaves with different water contents and thickness from different plants were obtained. The transmittance spectra were obtained by the portable instrument. The water contents were determined by weighing method. The quantitative relationship of the water contents and AD transformed near infrared spectral signal was established, and is shown in Figure 10. Plan two, one hundred of leaves with different water contents but same thickness from same plants were obtained. The transmittance spectra were obtained by the portable instrument. The water contents were determined by weighing method. The quantitative relationship of the water contents and AD transformed near infrared spectral signal was established, and is shown in Figure 11.

In Figure 8, it can be seen that the R^2 was 0.641 between the water contents and AD transformed near infrared spectral signal in plan one, showing that the model is not satisfied for the application. The R^2 was 0.866 between the water contents and AD transformed near infrared spectral signal in plan two. The results show that

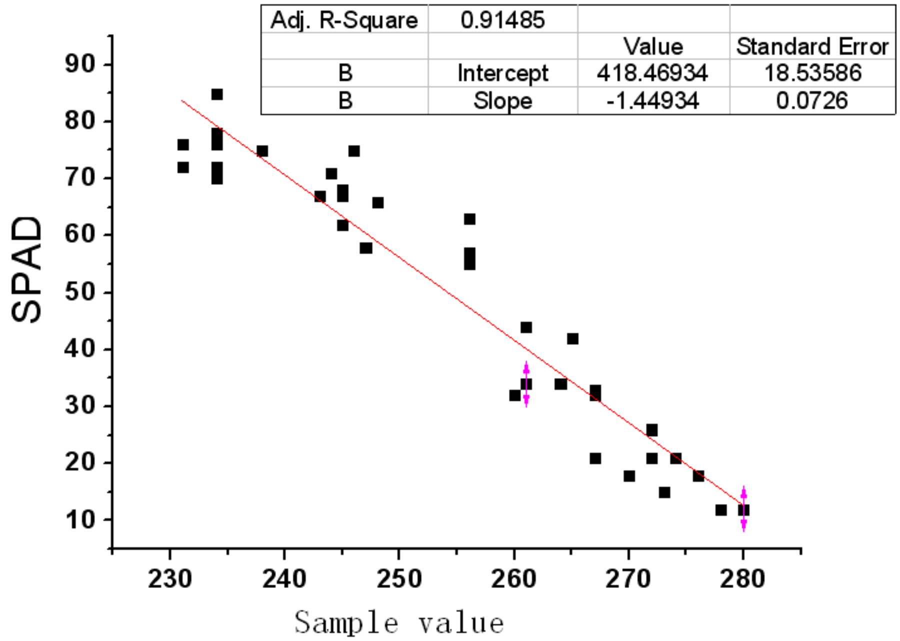

Figure 6. Linear relationship plot of AD signal and SPAD measured signal.

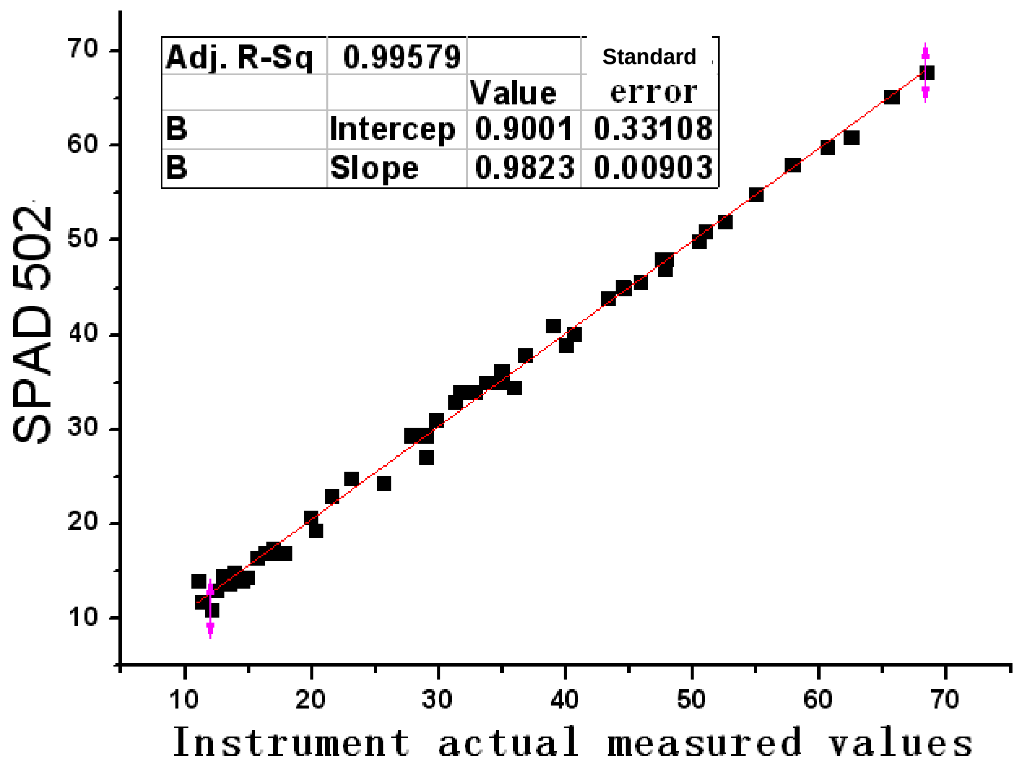

Figure 7. Relationship of the data predicted by the portable instrument and the SPAD measured data.

when the AD transformed near infrared spectral signals were used to measure the water contents of leaves with different thickness and species, the accuracy and reliability were not good. Therefore we upload the water content prediction models for different kinds of plants into the water content prediction system in the instrument to solve the influence of leaf thickness for the water content prediction.

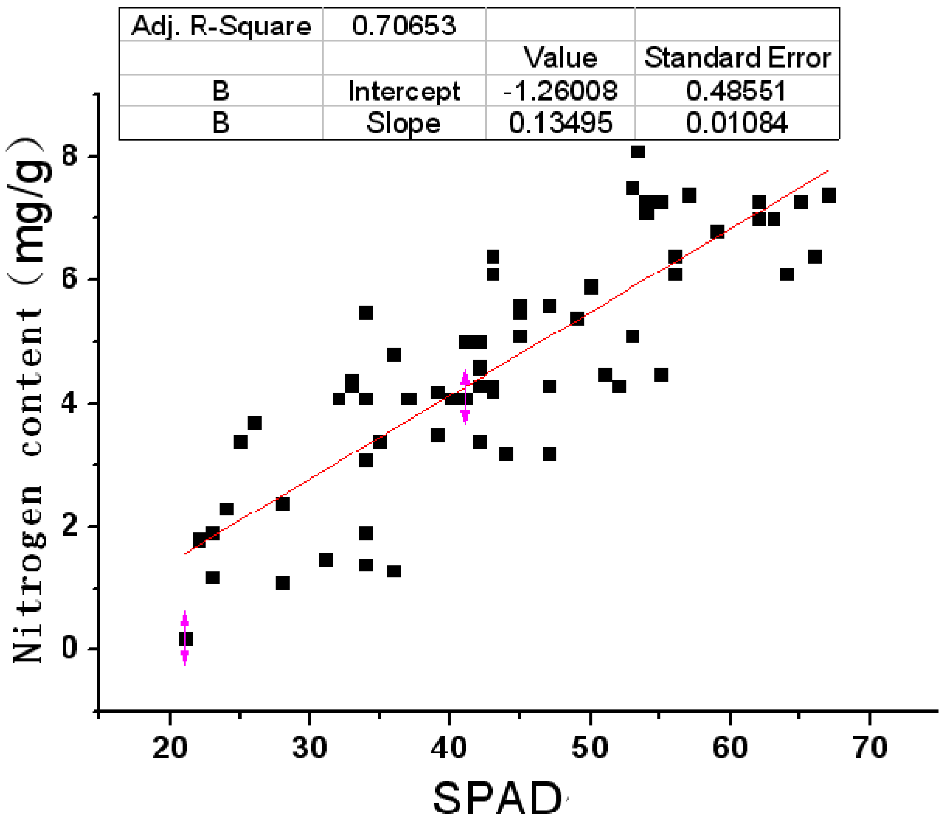

Figure 8. Relationship of chlorophyll contents and nitrogen contents obtained in plan one.

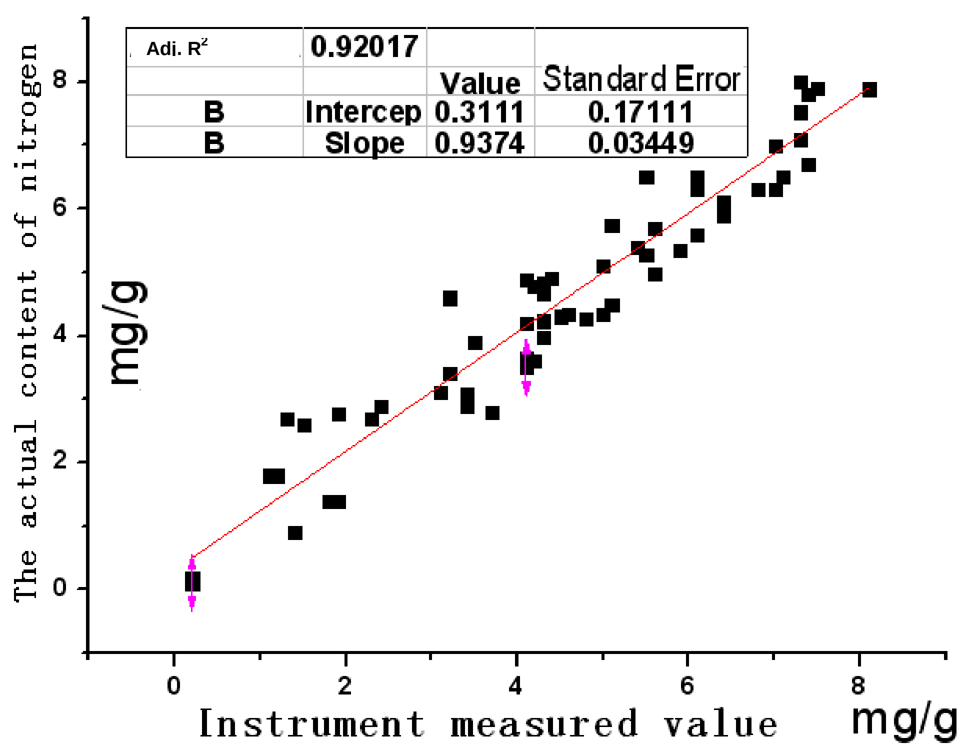

Figure 9. Relationship of predicted values and reference nitrogen contents in plan two.

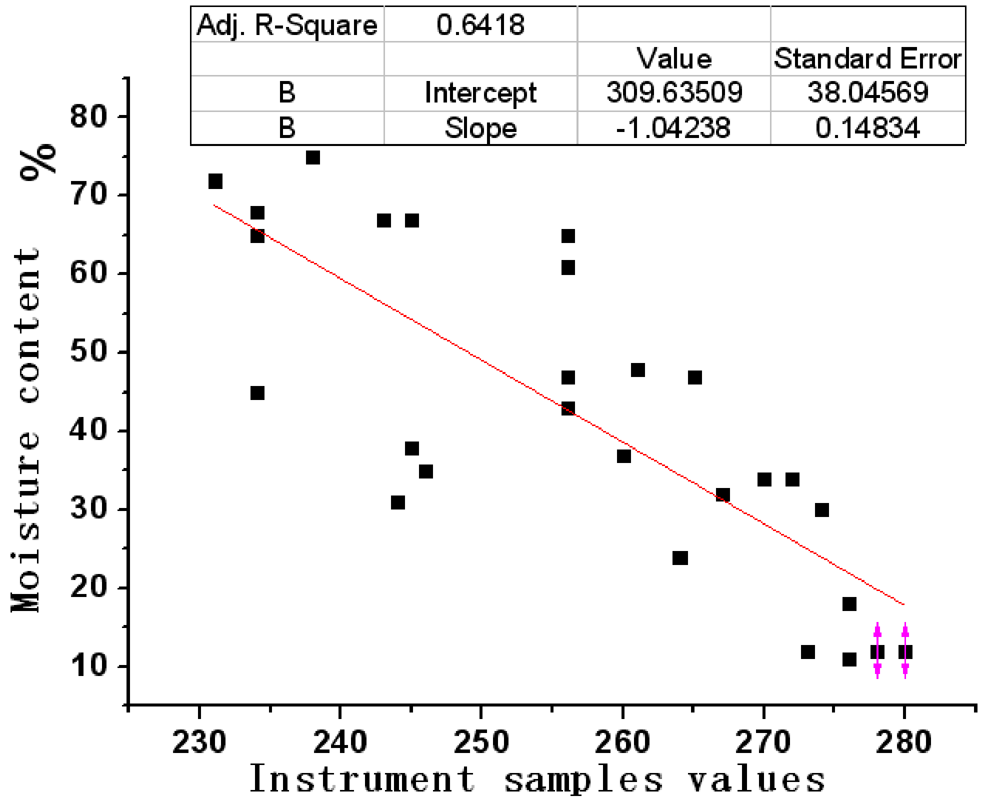

Figure 10. Relationship of the water contents and AD transformed near infrared spectral signal in plan one.

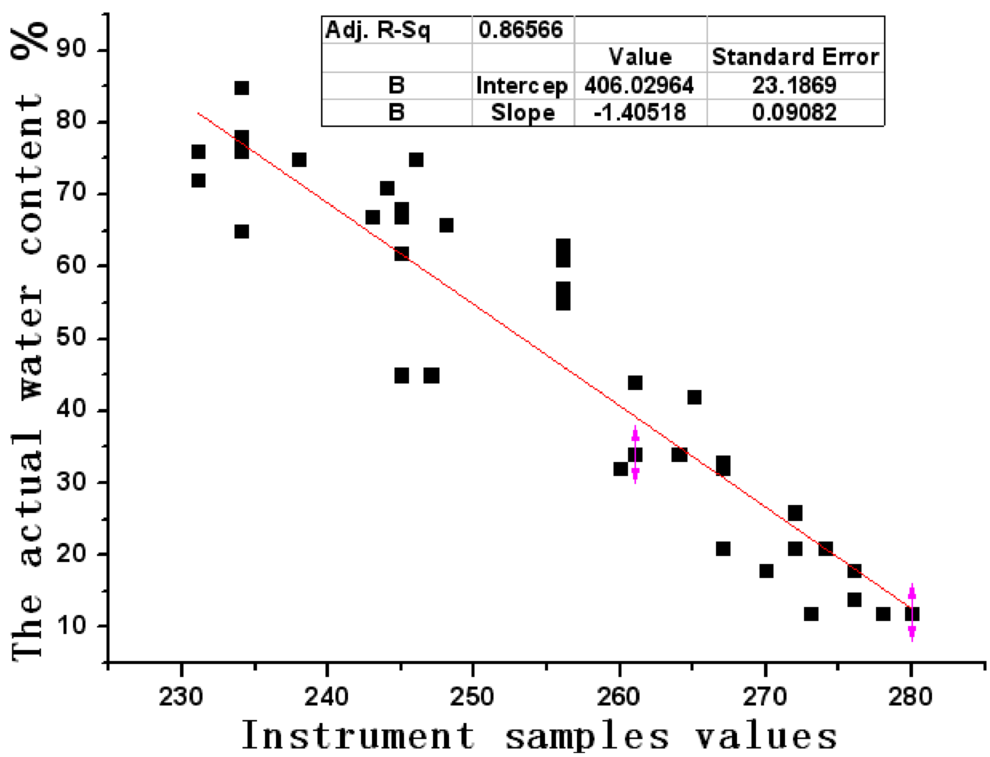

Figure 11. Relationship of the water contents and AD transformed near infrared spectral signal in plan two.

RESULTS AND DISCUSSION

In this paper, the advantages of NIR spectroscopy were obvious: it was a feasibly quick and nondestructive technique for measurement the leaf nutrition content. We designed the plant nutrition test instrument. The nutrition measurement of plant can much improve the measurement efficient and reduce the measurement cost. The instrument has the advantages of being easy to operate, light to carry, and with high measurement accuracy and stability performance. Based on the operation demand, several modules were designed, which include the optical systems, data acquisition, computing, wireless data transmission, GPS positioning module. The quantitative models for the plant nutrition measurement were established based on the measured spectra at two wavelengths.

The results of mass experiments and applications show that the measurement errors were 0.2 SPAD for the chlorophyll content measurement, 0.08 mg/g for the nitrogen content measurement, and 4% for the water content measurement. The instrument has a good repeatability and well stability. Meanwhile the instrument can work with GIS for the large-scale filed crop nutrition information management, which is the basic part for the field automatic operation in the modern precision agriculture. Still the instrument needs to be improved, such as the photoelectric sensor and LEDs in the instrument can be influent by the environment temperature, the battery capacity needs to be enlarged, and the instrument needs to have an automatic validation module, to make sure the instrument is more stable and reliable and has a better ability to adapt the environment.

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