

作物群落用反射スペクトル解析装置の開発(5):

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著者	芝山, 道郎 秋山, 侃 棟方, 研
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A Spectroradiometer for Field Use

V. A portable spectrophotometer—design and performance**

Michio SHIBAYAMA, Tsuyoshi AKIYAMA and Ken MUNAKATA*

(National Institute of Agro-Environmental Sciences,
Yatabe, Tsukuba, Ibaraki 305, Japan)

* : National Agriculture Research Center, Yatabe,
Tsukuba, Ibaraki 305, Japan)

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Spectral reflectance measurement for crop canopy seems to be one of promising methods because it is a nondestructive way to take information from a wide canopy area in a short time. We reported possibilities of radiometrical remote sensing for biomass and grain yield of paddy rice in field conditions^{4,5)} by using a computerized spectroradiometer for field use³⁾. The radiometer, however, was rather heavy and needed to be loaded on a gantry crane for measurements. Therefore, a portable-type spectrophotometer was purchased and connected with a microcomputer at our laboratory to obtain spectrum easily from various crop fields. A traveling crane system was also devised for placing the photometer above crop canopies (platform).

Some of the specifications, method of the operation of the measuring system, and sample data will be reported in this paper.

Design of the system

A photo and an illustration of the measuring instruments are presented in Figs. 1 and 2, respectively. The specification of the system is summarized in Table 1.

1. Platform

In field radiometric measurements, nadir observations are recommended because the look angle of the sensor may much affect on the output data⁶⁾. Therefore, an equipment which places the sensor about a few meters above the canopy without stepping into the plot site, is required. Therefore, the authors drew specifications of a motorized crane truck and Miyoshi Kikai Corp. designed and built it.

The photo of the crane is shown in Fig. 3. An oil-hydraulic crane boom of 5.8 m long (maximum) is mounted on the bed of a small cart which is hauled by a tractor (8.5 PS/3,600 rpm). The sensor-mount is hinged to the top of the boom so that the photometer on the sensor-mount always looks vertically toward the ground in spite of the lift angle of the boom. The motorized crane is so small (2.6 m × 1.1 m) that measurements can be made from a narrow footpath in paddy fields.

2. Optical system

The photometer is a model 2702IR manufactured by Abe Sekkei Corp. in Tokyo. The sensor unit (Su) is housed in a compact metal case (W 190 × H 136 × D 430 mm). Light passes through an objective lens (O ; 50 mm, F/1.8) to the monochromator. The plot site in the field of view (FOV) can be directly observed by the operator using an eye piece (E) of the parallax-free finder. The FOV is 9.4° × 1.1° and the slit width is 1 mm.

The diffraction grating in the monochromator is a product of Jobin Yvon, France (Model H-20IR). The focal length is 200 mm, and the wavelength range is from 400 to 1,200 nm. The diffraction grating is rotated by an electric motor at the rate of 20 nm/sec (maximum).

3. Electronics

The light detector for the 400—680 nm range is a photomultiplier (Model R928, Hamamatsu Photonics) and a silicon photocell (Model S874-5K, Hamamatsu Photonics) for the range of 680—1,200 nm.

The control unit (Cu ; W 434 × H 148 × D 391 mm) which is also a product of Abe Sekkei, is powered from 100 V AC (50—60 Hz) primary circuit and supplies stabilized DC to Su and digital circuits in Cu.

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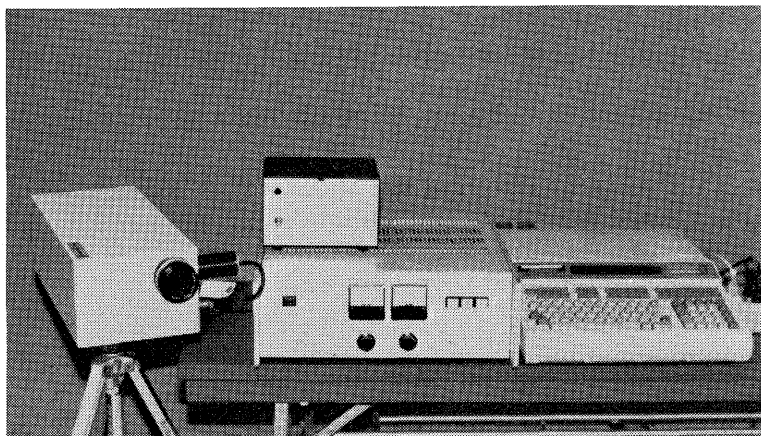


Fig. 1. Photograph of the portable spectrophotometer with the data logging system.

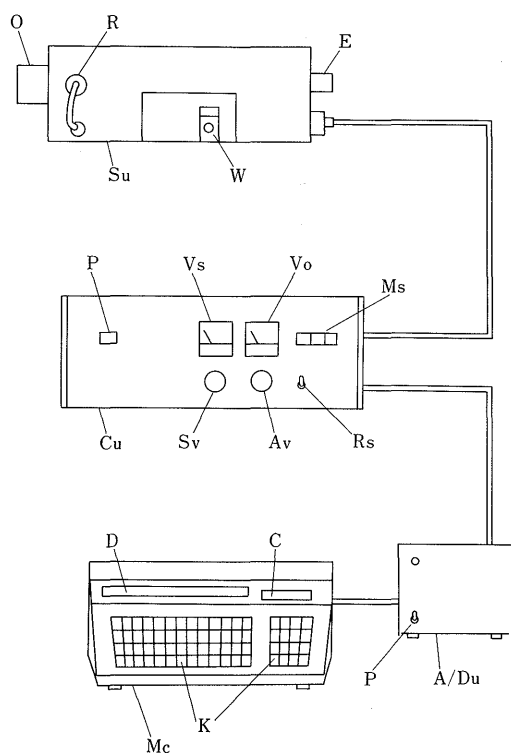


Fig. 2. Illustration of the portable spectrophotometer for field use.

Su : sensor unit ; O : objective lens ; R : reference lamp ; W : wavelength indicator ; E : eye-piece ; Cu : control unit ; P : power switch ; Vs : voltmeter for the high voltage power supply ; Vo : voltmeter for output ; Sv : high voltage selector ; Av : voltage adjuster ; Rs : reference lamp switch ; Ms : scan switch ; A/Du : analog-to-digital converter unit ; Mc : microcomputer (YHP Model 9825A) ; D : character display ; K : key board ; C : digital data cassette.

The high voltage supplied for the photomultiplier is 220 V. The high voltage adjusters (Sv, Av) on the panel of the Cu need to be adjusted to equalize the sensitivities of the two detectors at the turn-over wavelength (680 nm).

Input signals from the detectors pass through a cable (4 m long) from Su to the logarithmic amplifier in Cu. The range and the slope of the amplifier are 10,000 : 1 and 1.0 V/decade, respectively. The output signal is DC voltage from 0 V to 4.0 V. Wavelength position is indicated as both DC voltage (0.4–1.2 V for 400–1,200 nm) and pulse signals (TTL level) which are sent from the monochromator at every 10 nm interval. The motor which rotates the grating starts when the external trigger command (TTL level) is sent from the microcomputer.

Analog-to-digital converter unit (A/Du) consists of a one-tip 12 bit binary A/D converter (Model ICL7109, Intersil) and power supply circuits (ICL7660 and VOLTEK 2011A). The measurable voltage range is from 0.0 V to 4.096 V and conversion rate is 7.5 conversion/second at the maximum. The wavelength pulse signals pass to the "RUN/HOLD" pin of ICL7109 to start conversion at every 10 nm. The binary data are transferred to the microcomputer (Mc) by referring the "STATUS" pin of ICL7109 in the data handshake procedure of the control program. The trigger command from the microcomputer for starting the rotation of the grating also passes through the circuit in A/Du and transferred to Cu.

4. Microcomputer (Mc)

A desktop microcomputer (Hewlett-Packard

9825A) is connected with A/Du using a 16 bit I/O parallel interface card (98032A). The microcomputer (128 kbyte memory) has a digital cassette tape drive (C; 210 kbyte), a character display (D), and a key board (K). The program is coded in HPL which is similar to BASIC. The time at each measurement (month, day, hour, minute, and second) can be read from a real time clock (98035A).

Operation and sample data

The photometer attaches to the sensor-mount at the top of an oil-hydraulic crane boom which is mounted on a motorized cart. The microcomputer, Cu, and A/Du can be loaded on the bed of the cart. The time for a scan is about 50 to 60 seconds which can be slightly changed by a variable-ohm in Cu.

Spectral reflectance factors were calculated as the ratio of canopy radiance to the radiance of a reference panel which is an aluminium plate (1 m × 1 m, 2 mm in thickness) sprayed with Kodak White Reflectance Coating (Fig. 4).

Reflectance factor at x nm (Rx) is calculated by using the following equation.

$$R_x = 10^{V_x - V_{ox}} \times 100\% \quad (1)$$

Here, V_x is the output voltage (V) when the photometer measures the reflection from the plot site and V_{ox} is the output voltage (V) when the photometer measures the reflection from the reference panel. Although the refer-

ence lamp (R) housed in Su (Fig. 2) was calibrated by the manufacturer, we do not need it to obtain reflectance factors in fields.

Spectral patterns for paddy rice canopies obtained using the portable spectrophotometer are presented in Fig. 5. The measurements were made for ten varieties of rice (*Oryza sativa* L.) on August 30, 1983. The varieties used were 'Koshihikari' (a; LAI=5.6), 'Minehikari' (b; LAI=5.1), 'Nipponbare' (c; LAI=7.1), 'Nanking 11' (d; LAI=5.0), 'Milyang 23' (e; LAI=3.3), 'H2871' (f; LAI=3.9), 'TORO' (g; LAI=5.9), 'Razza 77' (h; LAI=3.0), 'Alborio' (i; LAI=3.2), and 'LT-18' (j; LAI=7.2). These patterns from 400 to 1,100 nm are reasonable as spectral signatures for crop canopies. Plot sites of higher LAI (leaf area index) showed higher reflectance factor in the near-infrared range. The spectral signatures above 1,100 nm, however, seemed somewhat discontinuous and unnatural. From these results of field measurement trials, the photometer and data logging system are considered to be usable in the wavelength region from 400 to 1,000 nm, although, field measurement data for the region from 1,000 to 1,200 nm do not seem to be always available.



Fig. 3. The motorized crane and the photometer used to obtain the spectral signatures from paddy rice canopies.



Fig. 4. The portable spectrophotometer measuring the reference panel (1 m × 1 m).

Discussion

The portable spectrophotometer and measuring system devised are highly usable under field conditions if 100 V AC primary circuit is available. The scan speed is much raised up to 15–20 nm/sec when it is compared with our former radiometer which scans 1.5 nm/sec³⁾. It makes possible to increase the repetition number of scan for each plot.

FUKUHARA et al. measured reflectance from wheat canopies using a filter-type portable spectroradiometer¹⁾. The spectrophotometer using a grating is considered to be usable in a study on searching effective wavelength bands because of its high wavelength resolution as was discussed by MIYAZAKI et al²⁾. It seems that this new instrument can take reliable spectral signatures of crop canopies from visible to near-infrared wavelength range (400–1,000 nm). The quality of data, however, in 1,000–1,200 nm region is not good enough prob-

ably due to the insufficient sensitivity of the silicon photo-cell. Another equipment should be designed for radiometrical field research covering mid-infrared range. Nevertheless, the portable spectrophotometer combined with the motorized crane and microcomputer may be well applicable in various field researches concerning crop growth diagnosis and remote sensing technique.

Summary

A field measuring system consisting of a portable spectrophotometer, wavelength range of which is from 400 to 1,200 nm, a mobile crane, and a microcomputer was devised for radiometrical studies on crop canopies.

A diffraction grating is rotated by an electric motor at a rate of 15–20 nm/sec and a photomultiplier and silicon photo-cell detect the light. A parallax-free view-finder is available.

An oil-hydraulic crane mounted on a cart

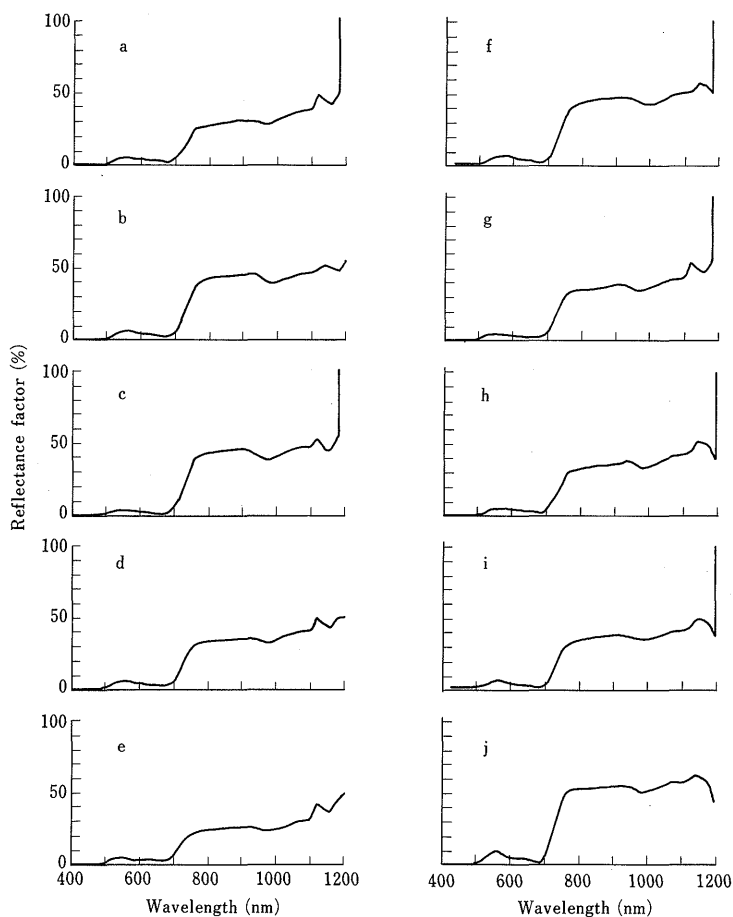


Fig. 5. Spectral patterns measured for paddy rice canopies on August 30, 1983, using the portable spectrophotometer and mobile crane.

a : Koshihikari, LAI=5.6 ; b : Minehikari, LAI=5.1 ; c : Nipponbare, LAI=7.1 ; d : Nanking 11, LAI=5.0 ; e : Milyang 23, LAI=3.3 ; f : H2871, LAI=3.9 ; g : TORO, LAI=5.9 ; h : Razza 77, LAI=3.0 ; i : Alborio, LAI=3.2 ; j : LT-18, LAI=7.2.

Table 1. Specification of the sensor unit and A/D converter unit of the portable spectrophotometer.

Light collection system	Lens and mirror
Field of view	9.4° × 1.1°
Diffraction grating	Jobin-Yvon H-20IR
Wavelength range	400-1200 nm
Focal length	200 mm
Method of mounting system	J-Y type
Slit width	1 mm
Reciprocal dispersion	600 lines/mm
F value	3.5
Light detection system	
Photomultiplier	Hamamatsu Photonics R928
Silicon photo-cell	Hamamatsu Photonics S874-5K
Logarithmic amplifier	Range is from 1 to 10000, and 1.0 V/decade
A/D converter	Intersil ICL7109 12 bit, 7.5 conversions/sec

with a gasengine was developed as a mobile platform to place the photometer above crop fields.

Output signals from the photometer are converted to digital data and stored in a microcomputer memory and digital data cassettes.

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* In Japanese with English summary.

〔和 文 摘 要〕

作物群落用反射スペクトル解析装置の開発

第5報 可搬型フォトメータを利用した移動分光計測システム

芝山 道郎・秋山 侃・棟方 研*

(農業環境技術研究所・* 現在農業研究センター)

小型で可搬型のスペクトロフォトメータをマイクロコンピュータに接続し、原動機付油圧クレーン車と組み合わせて野外用移動分光計測システムを製作した。

フォトメータは回折格子方式で400~1,200 nmを連続走査し、光電子増倍管とシリコン光電池で光電変換する。50 mm対物レンズで集光し、ファインダで対象と視野範囲(1.1°×9.4°)を確認できる。測定出力は対数増幅器を経て、12ビットA/D変換器でデジタル化され、デスクトップ型マイクロコンピュータに読み込まれる。測定部およびコンピュータの写真とブロック図を各々第1図と第2図に示す。また、光学系と電気系の主な諸元を第1表に掲げた。

このフォトメータを圃場上空数メートルの位置で下向きに保持するための補助装置(Platform)として、第3図に示したような小型クレーン車を製作した。ブームの最大長5.8メートルで油圧で昇降・起伏する。ブームの先端には起伏角に拘らずフォトメータが真下を向くようなセンサ基台が取り付けられている。また、高所からのフォトメータの較正用に、1メートル四方の大型標準白板(第4図)を用意した。

このシステムにより測定した水稻10品種の個体群からの反射スペクトルを第5図に示した。野外でのテストの結果400 nm~1,000 nmの波長範囲では安定した測定ができるが、1,000 nm以上では光検知器の感度が落ちるためデータの信頼性がやや低下することが明らかになった。しかし、このシステムを使用することにより、作物個体群の反射スペクトルを迅速に(走査時間約50秒)、しかも圃場内に踏み込むことなく取得できる見通しを得た。