J Soils Sediments (2008) 8:323–326
DOI 10.1007/s11368-008-0030-4

Hyper-spectral remote sensing to monitor vegetation stress

Hong-Yan Ren · Da-Fang Zhuang · Jian-Jun Pan · Xue-Zheng Shi · Hong-Jie Wang

Received: 3 March 2008 / Accepted: 17 August 2008 / Published online: 18 September 2008

Abstract
Background, aim, and scope Vegetation stress diagnoses based on plant sampling and physiochemical analysis using traditional methods are commonly time-consuming, destructive and expensive. The measurement of field spectral reflectance is one basis of airborne or spaceborne remote sensing monitoring.
Materials and methods In this study, paddy plants were grown in the barrels evenly filled with 10.0 kg soil that was mixed respectively with 0, 2.5×207.2 and 5.0×207.2 mg Pb per 1,000 g soil. Rice canopy spectra were gathered by mobile hyper-spectral radiometer (ASD FieldSpec Pro FR, USA). Meanwhile, canopy leaves in the field-of-view (FOV) of spectroradiometer were collected and then prepared in the laboratory, (1) for chlorophyll measurement by Model 721 spectrophotometer, and (2) for Pb determination by atomic absorption spectrophotometer (SpectraAA-220FS).
Results and discussion Canopy spectral reflectance in the region of visible-to-near-infrared light (VNIR) increased, because ascended Pb concentration caused the decrease of canopy chlorophyll content. In the agro-ecosystem, however, heavy metal contamination is presented typically as mixture and their interactions strongly affect actually occurring effects. Normalized spectral absorption depth (D_n), and shifting distance (DS) of red edge position (REPs) revealed the differences in Pb concentration for canopy leaves, especially at the early tillering stage. Due to insufficient biomass of rice plants, the 30th day was not reliable enough for the selection of crucial growth stages. Some special sensitive bands might be omitted at the same time because of limited sample sets.
Conclusions Our initial experiments are still too few in the amounts of both metals and plants neither to build accurate prediction models nor to discuss the transformation from ground to air/spaceborne remote sensing. However, we are pleased to communicate that ground remote sensing measurements would provide reliable information for the estimation of Pb concentration in rice plants at the early tillering stage when proper features (such as DS and D_n) of reflectance spectra are applied.
Recommendations and perspectives Hyper-spectral remote sensing is a potential and promising technology for monitoring environmental stresses on agricultural vegetation. Further ground remote sensing experiments are necessary to evaluate the possibility of hyper-spectral reflectance spectroscopy in monitoring different kinds of metals' stress on various plants.

Keywords Agricultural soil · Pb contamination · Reflectance spectroscopy · Rice · Vegetation stress

Responsible editor: Willie Peijnenburg

H.-Y. Ren · X.-Z. Shi · H.-J. Wang
State Key Laboratory of Soil and Sustainable Agriculture,
Institute of Soil Science, Chinese Academy of Sciences,
Nanjing 210008, People's Republic of China

H.-Y. Ren
e-mail: renhy@issas.ac.cn

H.-Y. Ren · J.-J. Pan (✉)
College of Resource and Environmental Sciences,
Nanjing Agricultural University,
Nanjing 210095, People's Republic of China
e-mail: jpan@njau.edu.cn

D.-F. Zhuang
Institute of Geographic Science and Resource Research,
Chinese Academy of Sciences,
Beijing 100101, People's Republic of China

1 Background, aim, and scope

Heavy metal contamination in agricultural soils is becoming more serious when much more waste residuals, waste water, and exhaust gas are released into agro-ecosystem (Douay et al. 2008; Ballach et al. 2002; Black and Williams 2001). Pb in the leaves displaces magnesium as the central atom of the chloroplast and affects the activity of enzymatics in the chlorophyll, which makes photosynthesis of plants weakened (Pruvot et al. 2006; Woxny and Krzeslowka 1993; Kupper et al. 1996; Yang et al. 2004). Compared to traditional methods for vegetation stress caused by heavy metal, hyper-spectral remote sensing is quicker, exact, and more comfortable, especially on a large scale (Pu and Gong 2000; Wei and Fang 2004; Yang et al. 2007; Broge and Mortensen 2002; George 1998). Field spectroscopy (namely ground remote sensing) can provide applications of airborne or spaceborne remote sensing with data support and pertinent correction reference. On the basis of spectral analysis, shifting distance (DS) of red edge position (REP, located in the region of 680~750 nm) and normalized spectral absorption depth (D_n) derived from continuum removal are widely applied (Dawson and Curran 1998; Moses and Andrew 2006; Hoque and Huntzler 1992; Smith et al. 2004; Shi 2006). Our objective was to explore the possibility of hyper-spectral reflectance spectroscopy in the estimation of Pb concentration in rice plants at an appropriate growth stage.

2 Materials and methods

In a green house of Nanjing Agricultural University, average five individual plants of rice (Xian_you 63) were cultivated in the barrels filled with 10.0 kg soil collected from a suburb area of Jintan City in Jiangsu Province. An experimental design was established with three labels of Pb concentration (0, 2.5×207.2, 5.0×207.2 mg Pb per 1,000 g soil) denoted as ‘Pb0’, ‘Pb1’ and ‘Pb2’, respectively.

At 10~14 o’clock in the sunny and cloudless days of 30, 50, 65, 80 and 90th, rice canopy spectra were collected by the mobile hyper-spectral radiometer (ASD Fieldspec Pro FR, USA), with a nadir view from a height of 0.5 m above rice canopy, using a 25° FOV (the field-of-view), which results in viewing an area of about 400 cm^2. These days were categorized as the seeding stage, early tillering stage, full tillering stage, jointing stage and booting stage of Xian_you 63.

Canopy leaves in the FOV of spectroradiometer were collected and then prepared in the laboratory, (1) for chlorophyll measurement by Model 721 spectrophotometer, and (2) for Pb determination by atomic absorption spectrophotometer (SpectraAA-220FS).

REPs were located at the maximums of first derivative reflectance spectra of rice canopy. Spectra of continuum removal were given by IDL/ENVI 4.2 (ESRI, Ltd. USA). Depth of absorption (D) and D_n were calculated by following formula. D_{max} represented the maximal D.

$$D = 1 - R'_{cr} \quad (1)$$

$$D_n = D/D_{max} \quad (2)$$

3 Results and discussion

REPs and DSs towards longer or shorter wavelength are summarized in Table 1. It shows that REPs of Pb2 paddy rice plants shifted towards shorter wavelength (blue light) by 22 nm on the 30th day, but DSs were equal to zero when paddy rice plants are on the 50th and 65th day with more and more exuberant vegetation, and then REPs of Pb2 shifted towards longer wavelength (red light) by 6 nm and 12 nm. In contrast, DSs of Pb1 were much less and not obvious.

The beginning and the terminal points were determined at 530 and 740 nm, respectively. Pb contamination also made the depth of absorption at 680 nm different between paddy rice plants of Pb0, Pb1 and Pb2. On the 50th day (Fig. 1a), D_n curve of Pb0 enveloped those of Pb1 and Pb2 from 530 to 740 nm, while on the 65th day (Fig. 1b) all three D_n curves went consistently, and then on the 80th day (Fig. 1c). The D_n curve of Pb0 was enveloped by both of Pb1 and Pb2 from 530 to 690 nm, but all of them also went consistently from 690 to 740 nm. D_n curves of Pb0 and Pb2 fluctuate identically (Fig. 2). Both maximal D_ns of Pb0 and Pb2 on the 50th day located at around 695 nm and those at other stages located at around 680 nm. In the region from 530 to 580 nm, D_n of Pb0 treatment (see Fig. 2a) on the 50th day was subjacent to other D_ns at the other stages, so did D_n of Pb2 treatment (see Fig. 2b) on the 50th day from 530 to 620 nm. It is also shown in Fig. 2a that D_n curve of Pb0 treatment on the 30th day was crossed with that on the

Table 1 REPs and DS (nm) in 1st derivative spectra in all growth stages

	30th	50th	65th	80th	90th
Pb0	721	738	730	718	731
Pb1	721	738	723	718	730
Pb2	699	738	730	724	719
DS	B=0, 22	0	B=7, 0	R=0, 6	B=1, 12

B REP shifts towards shorter wavelength (blue light), *R* REP shifts towards longer wavelength (red light). *DS* distance of shift and unit is nanometer

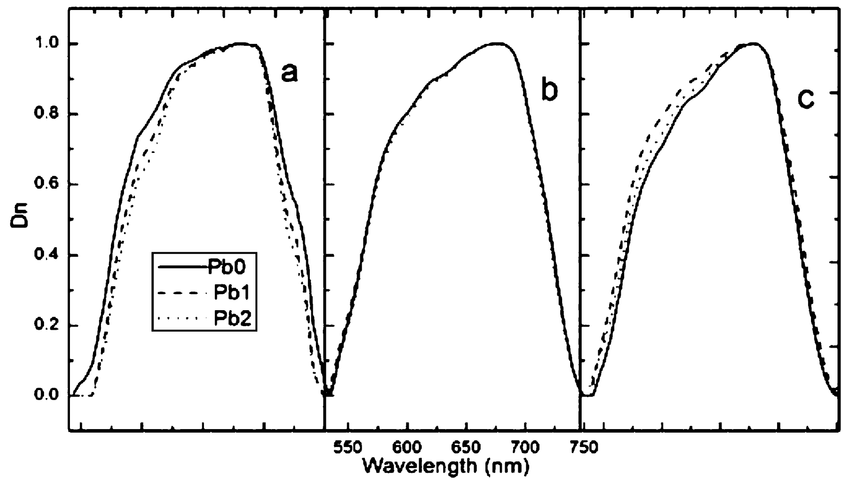

Fig. 1 D_n curves of Pb0, Pb1 and Pb2 treatment in the 50th (*A*), 65th (*B*) and 80th day (*C*)

50th day at around 580 nm. In Fig. 2b, at around 620 nm, so did D_n of Pb2 treatment. From the crossing point to the maximum, D_ns on the 50th day of both of Pb0 and Pb2 treatment ascended and then was higher than the other four stages. At the wavelength of 755 nm, D_n curves at other three stages are enveloped by those on the 30th day (inner) and the 50th day (outer).

Because of less biomass of rice plants on the 30th day, Pb concentration in plants is not accurate enough to report real condition of Pb contamination in soils so that this sampling stage is not reliable enough for the selection of crucial growth stages. Further ground remote sensing experiments are necessary to evaluate the possibility of hyper-spectral reflectance spectroscopy in monitoring different kinds of metals' stress on various plants.

By means of some fitting methods like partial least square (PLS; Leone and Sommer 2000), furthermore, accurate prediction of heavy metal concentration in crops would be evaluated by quantitative equations based on both heavy metal contamination and hyper-spectral data (DS, D_n, vegetation index and so on).

4 Conclusions

Our initial experiments are still too few in the numbers of both metals and plants, neither to build accurate prediction models nor to discuss the transformation from ground to air/spaceborne remote sensing. However, we are pleased to communicate that ground remote sensing measurements would provide reliable information for the estimation of Pb concentration in rice plants at the early tillering stage when appropriate features (such as DS and D_n) of reflectance spectra are applied

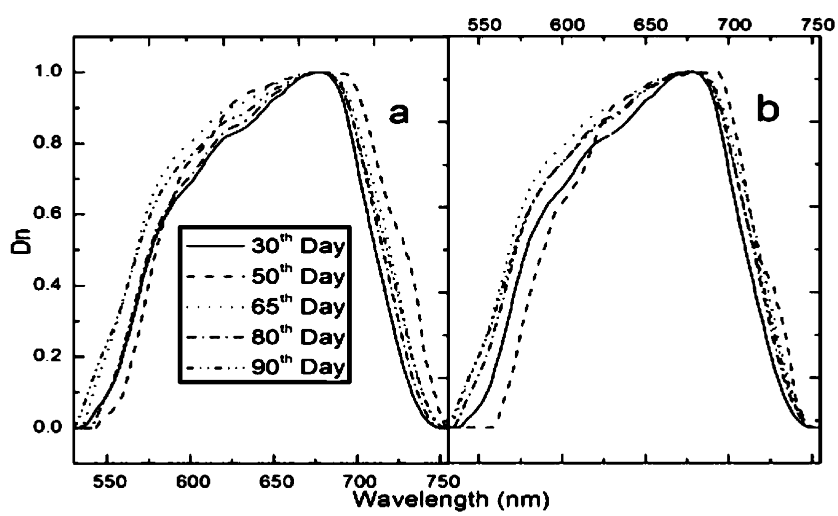

Fig. 2 All D_n curves of Pb0 (*A*) and Pb2 (*B*) treatment at five stages

Acknowledgements This work was supported by the National Natural Science Foundation of China (No.40231016), the National Natural Science Foundation of China (No. 40621001) and the Frontier Project of the Chinese Academy of Sciences (No. ISSASIP0715). We thank Dr. Zhang Jie and Dr. Anand for their significant help during chemical analyses of this study as well as Professor Tian Qing-jiu and Dr. Lu Ying-cheng for their technical assistance.

References

Ballach H-J, Wittig R, Wulff S (2002) Twenty-five years of biomonitoring lead in the Frankfurt/Main Area. Environ Sci Pollut Res 9(2):136–142

Black M, Williams P (2001) Preliminary assessment of metal toxicity in the middle Tisza River (Hungary) flood plain. J Soils Sediments 1(4):213–216

Broge NH, Mortensen JV (2002) Deriving green crop area index and canopy chlorophyll density of winter wheat from spectral reflectance data. Remote Sens Environ 81:45–57

Dawson TP, Curran PJ (1998) A new technique for interpolating the reflectance red edge position. Int J Remote Sens 19:2133–2139

Douay F, Roussel H, Pruvot C, Waterlot C (2008) Impact of a smelter closedown on metal contents of wheat cultivated in the neighbourhood. Environ Sci Pollut Res 15(2):162–169

George AB (1998) Quantifying chlorophylls and caroteniods at leaf and canopy scales: an evaluation of some hyperspectral approaches. Remote Sens Environ 66:273–285

Hoque E, Huntzler JS (1992) Spectral blue shift of red edge monitors damage class of beech trees. Remote Sens Environ 39:81–84

Kupper H, Kupper F, Spiller M (1996) Environmental relevance of heavy metal substituted chlorophyll using the example of water plants. J Experim Botany 47:259–266

Leone AP, Sommer S (2000) Multivariate analysis of laboratory spectra for the assessment of soil development and soil degradation in the Southern Apennines (Italy). Remote Sens Environ 72:346–359

Moses AC, Andrew KS (2006) A new technique for extracting the red edge position from hyperspectral data—the linear extrapolation method. Remote Sens Environ 101:181–193

Pruvot C, Douay F, Fourrier H, Waterlot C (2006) Heavy metals in soil, crops and grass as a source of human exposure in the former mining areas. J Soils Sediments 6(4):215–220

Pu RL, Gong P (2000) Hyper-spectral remote sensing and its applications. Higher Education, Beijing, p 8

Shi RH (2006) Study on quantitative inversion of plant biochemical information with hyperspectral data. Graduate University of CAS, June

Smith KL, Steven MD, Colls JJ (2004) Use of hyperspectral derivative ratios in the red-edge region to identify plant stress responses to gas leak. Remote Sens Environ 92:207–217

Wei HY, Fang YM (2004) Review on bryophyte and airborne heavy metal pollution biomonitoring. J Nanjing Forestry Univ 28:77–81 (in Chinese)

Woxny A, Krzeslowka M (1993) Plant cell response to Pb. Acta Soc Bot Pol 62:101–105

Yang QW, Shu WS, Qiu JW, Wang HB, Lan CY (2004) Lead in paddy soils and rice plants and its potential health risk around Lechang lead/zinc mine, Guangdong, China. Environ Int 30:883–89

Yang CM, Chen CH, Chen RK (2007) Changes in spectral characteristics of rice canopy infested with brown planthopper and leaffolder. Crop Sci 47:329–335