View metadata, citation and similar papers at core.ac.uk

brought to you by CORE

provided by Siberian Federal University Digital Repository

Journal of Siberian Federal University. Engineering & Technologies, 2019, 12(5), 617-622
~ ~ ~

УДК 528.855

Using Ground-Based Spectrometry for Operational Monitoring of Crop Yields

Anatoly P. Shevyrnogov,
Irina Yu. Botvich and Tamara I. Pisman*
Institute of Biophysics SB RAS
FRC «Krasnoyarsk Science Center SB RAS»
50/50 Akademgorodok, Krasnoyarsk, 660036, Russia

Received 24.06.2019, received in revised form 02.07.2019, accepted 09.07.2019

The purpose of this study is to analyze the relationship between crop yields and total chlorophyll potential of different barley and oats cultivars. For this purpose, we used the spectra of grain crops obtained from ground-based remote sensing, and laboratory data. Ground-based data were obtained at the experimental fields located in the Krasnoyarskii Krai. Experiments were carried out in different seasons and under various lighting conditions. Spectral measurements were done with a double-beam spectrophotometer. It was installed on the mobile work platform at heights of 5 to 18 m. The study showed good correlation between crop yields and total chlorophyll potential for barley and oats cultivars.

Keywords: ground remote sensing, yield, total chlorophyll potential, barley, oats.

Citation: Shevyrnogov A.P., Botvich I.Yu., Pisman T.I. Using ground-based spectrometry for operational monitoring of crop yields, J. Sib. Fed. Univ. Eng. technol., 2019, 12(5), 617-622. DOI: 10.17516/1999-494X-0161.

Применение наземного спектрометрирования для оперативного мониторинга урожайности сельскохозяйственных культур

А.П. Шевырногов, И.Ю. Ботвич, Т.И. Письман
Институт биофизики СО РАН
ФИЦ «Красноярский научный центр СО РАН»
Россия, 660036, Красноярск, Академгородок, 50/50

Целью данного исследования является анализ связи между урожайностью и суммарным хлорофилльным потенциалом посевов ячменя и овса. Для этого были использованы спектры

© Siberian Federal University. All rights reserved
This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License (CC BY-NC 4.0).
* Corresponding author E-mail address: ap_42@mail.ru, irina.pugacheva@mail.ru

зерновых культур, полученные при наземном дистанционном зондировании, и лабораторные данные. Наземные данные были получены на экспериментальных полях, расположенных в Красноярском крае. Эксперименты проводились в разные сезоны, при различных условиях освещения. Спектральные измерения осуществляли с использованием двухлучевого спектрорадиометра. Он был установлен на подвижной платформе на высоте от 5 до 18 м. Проведенное исследование показало хорошую корреляцию между урожайностью и суммарным хлорофилльным потенциалом для различных сортов ячменя и овса.

Ключевые слова: наземное дистанционное зондирование, урожайность, суммарный хлорофилльный потенциал, ячмень, овес.

Introduction

Remote sensing techniques are an effective tool of monitoring farm crops [1]. To evaluate the yields of farm crops by remote sensing techniques, the plants need to be continuously monitored during their growing season. Reliable monitoring should be based on the crop data with a relatively high temporal resolution (every 5-8 days). Parameters characterizing the physiological state of the plants (yield) during their growing season should be evaluated quickly [2].

The classical method of evaluating the state of the crops is based on NDVI [3]. In this research they evaluated the use of the MODIS NDVI and surface temperature products to develop a multi-dimensional regression algorithm to predict the state and county level yields.

The NDVI seasonal dynamics is representative of crop growth and biomass changes and thermal data is representative of the crop moisture stress condition [4]. Vegetation indices are usually calculated by using plant reflectance at two wavelengths. Ground – based measurements are necessary for decoding and interpreting the data obtained from satellites [5].

The purpose of this study was to investigate the relationship between crop yields and total chlorophyll potential of barley and oats based on reflectance spectra obtained by ground – based remote measurements.

Material and methods

Barley (*Horde disticxon* L.) and oats (*Avena sativa* L.) crops were investigated in this study. These crops differ in their grain yield, chlorophyll content, and time to maturity. They are commonly grown in Russia, and their physiology has been sufficiently studied.

Field studies were performed on fields situated in the central and southern regions of the Krasnoyarskii Krai (Russia) during the growing seasons of between 2002 and 2012. The studies were conducted on 200 – 600 m^2 experimental plots. The plots differed in the amounts of fertilizers added to the soil per square meter [6]. The plots were located rather close to each other, i.e. in the same climatic conditions.

The calculation of total chlorophyll potential was based on registration of the reflectance factor, ρ_λ, of the crops using a PDSP double-beam spectrophotometer installed on the elevated work platform at heights of 5 to 18 m under sunny conditions [7].

To assess the crop yields at the end of the growing season used the total chlorophyll potential (equation 1).

$$\sum S(t) = \int_{t_0}^{t} \left[90 \cdot \left(\rho_{730}(t) + \rho_{550}(t) \right) - \int_{550}^{730} \rho(\lambda, t) d\lambda \right] dt, \quad (1)$$

where 90 is the multiplier equal to the half – width of the chlorophyll absorption band between 550 and 730 nm, ρ_{550} and ρ_{730} are values of the reflectance factor of the plant canopy at λ = 550 nm and λ = 730 nm.

The yields of barley and oats on the study plots were determined by weighing the grains collected from 2 m^2 simultaneously with the remote measurements of the reflectance factor.

Results and discussion

Variations in the reflectance factor of oats and barley crops over the growing season are shown in Fig. 1 and Fig. 2.

As plants developed, their color changed from bright green in the early phase of development (June) to bright yellow at the end of the growing season (August). In the early phase of plant devel-

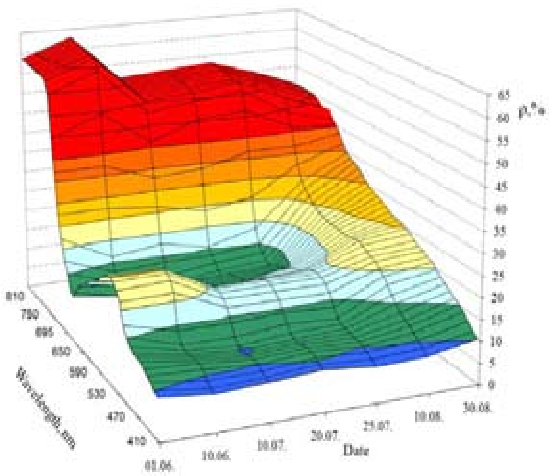

Fig. 1. Spectral reflectance characteristics throughout the growing season of oats

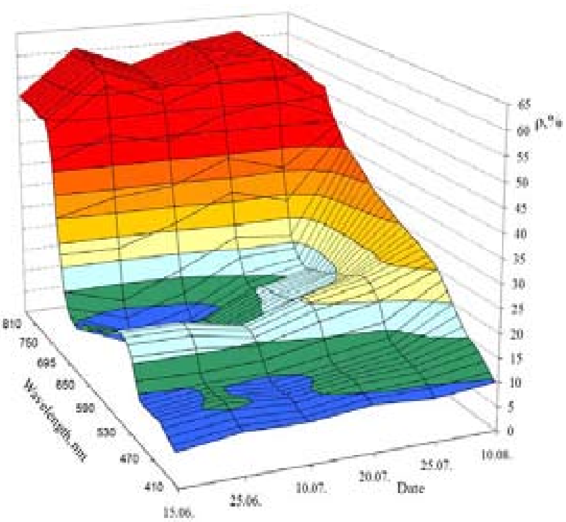

Fig. 2. Spectral reflectance characteristics throughout the growing season of barley

opment, plant reflectance factor had two distinct minima at 400 nm and 680 nm. The values of the reflectance factor could reach 60-65% at 800 nm and 20-25% at 550 nm, while at 400 nm and 680 nm, they varied between 4 and 8% (Fig. 1 and Fig. 2). In middle of July the crops differed in their optical properties and the amounts of pigments in plants. As plants developed, their vegetative biomass built up, and the reflectance factor in the region between 620 and 730 nm increased. That was caused by the chlorophyll decrease in the crops. Both crops showed similar variations in the values of the reflectance factor, but they differed in the values of absorption of radiant energy in the green and near – infrared regions. The reflectivity of barley was higher than the reflectivity of oats in the near-infrared spectral region (λ = 730 – 810 nm). In that period, the pigment ratios changed rapidly, and ear development consumed the assimilates. The reflectance factor in the red region (680-730 nm) increased at a higher rate than the reflectance factor in the shortwave region (400-460 nm). By the end of the growing season, the plants had turned completely yellow, the grain in the ears had ripened, and there was almost no chlorophyll in the plants. Analysis of the spectra showed that in that phase, reflectance factors in the wavelength range between 550 and 730 nm had changed more substantially than in other phases of the growing season and that they were essentially determined by the amounts of pigments (total chlorophyll) in the plants (the red absorption spectrum of chlorophyll "a" λ_{max}= 680 nm). That was mainly caused by intense processes of accumulation and breakdown in plants, which may be used as indicators of changes occurring in them. Barley has shorter time to maturity (Fig. 2), than oats (Fig. 1), and chlorophyll breakdown in the oat plants in the red absorption spectrum (λ = 680 nm) is 8-10 days delayed compared to barley. Thus, seasonal variations in the reflectance factor, ρ_λ, of the crops can be used to identify plant species and evaluate the physiological state of the plants.

Investigations of correlations between the yield of barley and oats crops and total chlorophyll potential were based on long-term data on crops grown on soils containing various amounts of fertilizers. To obtain accurate and reliable estimates of these parameters, they were measured and calculated for ten years, under different growing conditions. Results of these investigations are shown in Fig. 3. The

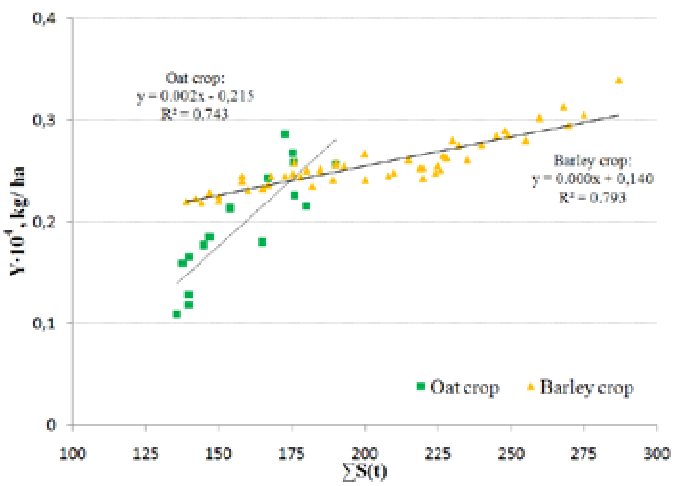

Fig. 3. Relationship between the crop yield and total chlorophyll potential of oats (based on the data for 17 fields) and barley (based on the data for 58 fields) during the growing season

value of total chlorophyll potential for barley is higher than its value for oats with yield contents being equal because of physiological differences between the crops. Barley leaves are broader than oats leaves, and during the active growing phase, the leaf area density of barley is higher than the leaf area density of oats.

Measurements showed good correlation between yield and total chlorophyll potential for barley and oat crops cultivated under different sowing and growing conditions. For barley crops, the coefficient of determination is $R^2 = 0.79$ and for oat crops $R^2 = 0.74$. However, correlation between chlorophyll potential and chlorophyll content of barley and oats crops is higher than correlation between total chlorophyll potential and crop yield [7]. Correlations obtained for one season with optimal plant growing conditions are higher than the average correlations based on the data obtained for ten years, as the crops were grown under dissimilar weather conditions. This correlation is indicating that reliable estimates of crop yield can be obtained by determining chlorophyll potential by the optical remote sensing method.

Conclusion

The study showed the effectiveness of using ground – based remote sensing to estimate yield of barley and oats crops based on the total chlorophyll potential calculated from the reflectance factor, ρ_λ. The effectiveness of the method was proved by a large number of field remote measurements and laboratory measurements. Monitoring of changes in the reflectance factor of barley and oat crops over the growing season showed their high information value in the region between 550 and 730 nm. This spectral range can be used to decode aerospace multispectral images [8, 9]. Ground-based remote measurements of the reflectance factors of barley and oat crops suggest the following conclusions.

The main results:

1. The study showed good correlation between crop yields and total chlorophyll potential for different varieties of barley and oats. The coefficient of determination for barley is $R^2= 0.79$ and for oats $R^2 = 0.74$.

2. The value of total chlorophyll potential for barley is higher than its value for oats with yield contents being equal.

References

[1] Migdall S., Bach H., Bobert J., Wehrhan M. and Mauser W. Inversion of a canopy reflectance model using hyperspectral imagery for monitoring wheat growth and estimating yield, *Precision Agriculture*, 2009, 10(6), 508-524

[2] Shapira H.U., Karnieli K.A., Bonfil D.J. Ground-level hyperspectral imagery for detecting weeds in wheat fields, *Precision Agriculture,* 2013, 14, 637-659

[3] Kouadio L., Newlands N.K., Davidson A., Zhang Y. and Chipanshi A. Assessing the Performance of MODIS NDVI and EVI for Seasonal Crop Yield Forecasting at the Ecodistrict Scale, *Remote Sens.*, 2014, 6(10), 10193-10214. DOI: 10.3390/rs61010193

[4] Doraiswamy P.C., Moulin S., Cook P.W. and Stern A. Crop yield assessment from remote sensing, *Photogrammetric Engineering and Remote Sensing*, 2003, 69, 665-674

[5] Sid`ko A.F., Botvich I.Yu., Pisman T.I., Shevyrnogov A.P. A study of spectral-polarization characteristics of plant canopies using land-based remote sensing, *Journal of Quantitative Spectroscopy and Radiative Transfer,* 2013, 129, 109-117

[6] Botvich I.Yu., Sidiko A.F., Pitman T.I., Shevyrnogov A.P. Determination of chlorophyll photosynthetic potential in vegetation using ground-based and satellite methods, *Journal of Siberian Federal University. Engineering & Technologies*, 2012, 5(1), 87-97

[7] Sid`ko A.F., Pisman T.I., Botvich I.Yu., Shevyrnogov A.P. Estimation of chlorophyll content of barley and oats crops based on reflectance spectra obtained by ground – based remote measurements, *Journal of Siberian Federal University. Engineering & Technologies,* 2016, 9(8), 1333-1339

[8] Thenkabail P.S., Smith R.B., and De-Pauw E. Evaluation of Narrowband and Broadband Vegetation Indices for Determining Optimal Hyperspectral Wavebands for Agricultural Crop Characterization, *Photogrammetric Engineering and Remote Sensing*, 2002, 68(6), 607-621

[9] Whitcraft A.K., Becker-Reshelf N., Brian D., Killough B.D., Justice C.O. Meeting Earth Observation Requirements for Global Agricultural Monitoring: An Evaluation of the Revisit Capabilities of Current and Planned Moderate Resolution Optical Earth Observing Missions, *Remote Sens*., 2015, 7(2), 1482–1503. DOI: 10.3390/rs70201482