EVALUATION OF DROUGHT STRESS DETECTION POSSIBILITIES BY SPECTRAL METHODS IN AN APPLE ORCHARD

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Abstract

An orchard can be examined on the basis of spectral data, using such methods with which the reflected radiation can be divided into a large number of (several hundreds) small spectral channel (some nm). Based on the spectral characteristics of the canopy, or the different index numbers calculated from hyperspectral data the water supply conditions of foliage can be well characterized. The research site is an intensive apple orchard, which located in Debrecen University, Centre for Agricultural and Applied Economic Sciences, Farm and Regional Research Institute at Pallag. During my experiments the evaluation of spectral, non-invasive measurement method are carried out for detecting stress symptoms caused by drought.

Key words: water content, drought stress, spectral measurements.

INTRODUCTION

Drought adaptation has a special significance in modern biomass production, in order to reduce production risks, to mitigate extreme water stress situations and to enhance food and crop safety. These goals can only be achieved by integrated complex approach in crop and fruit production as well as rural development (Juhász et al., 2013). Hungary has favourable agro ecological potential for pomaceous fruit production (Soltész, Szabó, 1998). Orchards are relatively not highly water consumer comparison with cereal species. However, to ensure optimal water capacity values calculating breeding season it is the most important risk factor. Therefore in large orchards up-to-date information is needed on water capacity and possible water stress of the fruit trees. The reason for this is that the physiological reactions against the changing water capacity appear much earlier than the water stress. These physiological changes cannot be observed visually in the early period of water stress. Thus early detection of the effect of different stressors, such as drought has a key role in the mitigation and prevention.

Natural or artificial stressors directly affect the chlorophyll content and cause changes in pigment content. According to Lichtenthaler (1998), measuring and monitoring of chlorophyll content important information can be obtained from the physiological status of the vegetation. Water and chlorophyll content of leaves, stressed by the effect of water deficit, decreases continuously with the progress of drought, therefore monitoring of vegetation, its chlorophyll content and vegetation indices are good indicators of photosynthetic activity, mutations, stress (Burai et al., 2009), degradation processes occurred in soils, and the state of plant nutrient, and this have a particular high significance in precision agriculture. There are several methods available to determine the chlorophyll content. Conventional chlorophyll measurement methods are destructive, time consuming and expensive. Thus reflectance measurements of leaves can be the solution for detection of changing water content. Hyper- and multispectral technology is widely used in agriculture and environmental protection, and is appropriate for vegetation analysis (Clark, 1999; Kruse, 2003; Milics et al., 2008; Polder et al., 2001; Sabins, 1997). The chlorophyll content is one of the indicators of the state of health (Burai et al., 2009), which affect the reflectance spectra of the vegetation and the vegetation indices as well. Minimum at the visible spectral range is related to pigments in plant leaves. Chlorophyll absorbs markedly spectral range between 450 – 670 nm. Healthy vegetation reflects the 40-50% of the incoming energy between 700-1300 nm spectral ranges due to the internal structure of the canopy, lignin content and parenchyma structure of the leaves (Gates et al., 1965). In this way, the measured reflectance plays an important role in distinguishing different plant species and possible water stress, even if these species are seems to be similar based on visible spectral range (Berke et al., 2004). In reference to this, searching areas referring to early recognisability of plant diseases, mapping of deficiency of nutrients by reflectance spectrum, the singular or association level approach of the vegetation in agro-ecological, cropping technologies respect, have to be mentioned (Santoso et al., 2011).

MATERIAL AND METHOD

The research was carried out at the University of Debrecen, Centre for Agricultural and Applied Economic Sciences, Research Institute for Farm and Regional Research Sciences at Pallag. The examination site is a microirrigated intensive apple orchard. The orchard is 0.68 ha (62m x 110m) with 4 m row and 1 m tree distance. All species were grafted on M9 stocks.

Since the orchard is situated on sandy soil with extreme water balance and water holding capacity, stress caused by drought can result especially high risk on yield. Stress, due to lack of water, or other diseases, can be observed firstly in the changes of chlorophyll and water content of the canopy, thus concerned characteristics of canopy leaf samples were measured in the experiment. Leaf samples were taken from the following apple species: Golden Reinders, Early Gold, Gala Galaxy, Gala Must, Pinova, Buckeye Gala, Gala Annaglo and Golden B from branches at 120 cm height, from five trees/species,

Goal of this study was to elaborate the spectral detectability of leaf characteristics concerning water stress. In order to achieve this goal, not only the spectral profiles of the leaf samples were measured, but also conventional gravimetric method for water content and destructive chlorophyll measurements were carried out as a calibration for the spectral features. The principal component analysis and bivariate correlation statistical methods were used to select that wavelength which relates to water or chlorophyll content. Tukey variance analysis was used to determine the differences between different water and chlorophyll content and detect spectral differences.

The spectral profiles (reflectance) were measured by laboratory scale AvaSpec 2048 spectrometer at 400 – 1000 nm wavelength interval with 0.6 nm spectral resolution. The AvaSpec 2048 system consists of one spectrometer, AvaLight-HAL halogen light source which are joined by a fibre optic with 8 μm diameter and a self-innovated special sampling box in order to provide dark for measurements (Figure 1).

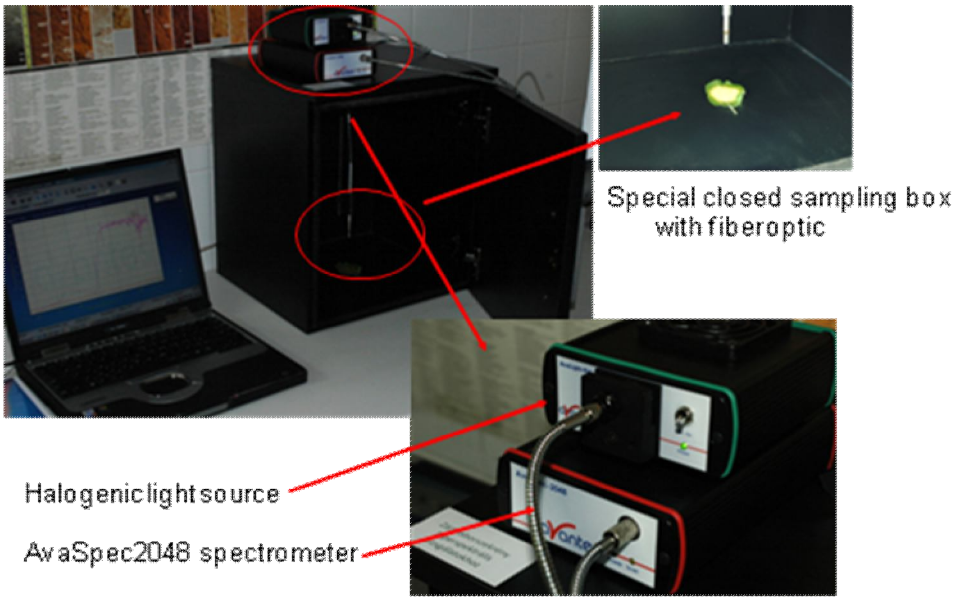

Fig. 1. AvaSpec 2048 system during measurement, and special sampling box

The halogen light source provides constant intensity of light emission on 400-1000 nm. The special sampling box is used to isolate samples from the permanently changing irradiation of other light sources (e.g. light bulb or neon or fluorescent lamp).

Before conventional measuring of chlorophyll content, relative chlorophyll content of the leaf samples were also measured by Konica Minolta SPAD in order to select samples with different pigment content for laboratory measurement and to decrease the amount of samples to save time and chemicals. After that fresh leaf samples were used for pigment measurements. The weight of leaf samples were about 80-100mg, leaves were destructed by 10 ml acetone for extraction and 1 g quartz sand for homogeneity. After extraction the suspensions were centrifuged, and the absorbance of the clean solution was measured by SECOMAN Anthelie Light II. UV-VIS spectrophotometer at 644 and 663 nm wavelength. Based on the absorbances chlorophyll content was calculated by the followings (Droppa et al., 2003):

$$Chlorophyll\ (a+b)\ \mu g/g\ fresh\ weight=(20{,}2*A644+8{,}02*A663)*\ V/w,$$

where: V = volume of tissue extract (ml), w = fresh weight of tissue (g), A = absorbance.

RESULTS AND DISCUSSION

The spectral profiles of apple leaves describe properly the spectral characteristics of healthy green vegetation (Figure 2). Chlorophyll absorbs markedly the electromagnetic radiations at 450-670nm wavelength interval, especially at green and red colour intervals. At 700 nm the reflectance increases steadily, and the leaves reflect the 60-80% of the light source energy between 700-1000 nm spectral ranges.

However, in practice, raw reflectance data can not be used without any limitation or filtering at the whole spectral, since reliable reflectance data with low noise (standard deviation below 3%) are obtained at 450-870 nm wavelength intervals. In order to utilize the whole interval, noise filtering by method of moving averages was carried out, thus the significant 6-8(10) percent spectral fluctuation in the near infra-red (NIR) range decreased to 1-3%. It can also be stated, that due to the noise of the measurements, but mainly to the thinness of the leaf samples, spectral differences are not observed in water sensitive 900-970 nm wavelength interval (Champagne et al., 2001), thus it is not possible to calculate the well–known Water Band Index. Therefore, other wavelength intervals were studied for water sensitive.

Comparing the reflectance properties to dry material content of leaf samples significant correlation can be found at 540-575nm (r~-0.610) as well as 750-830 nm (r~0.8) (Figure 3).

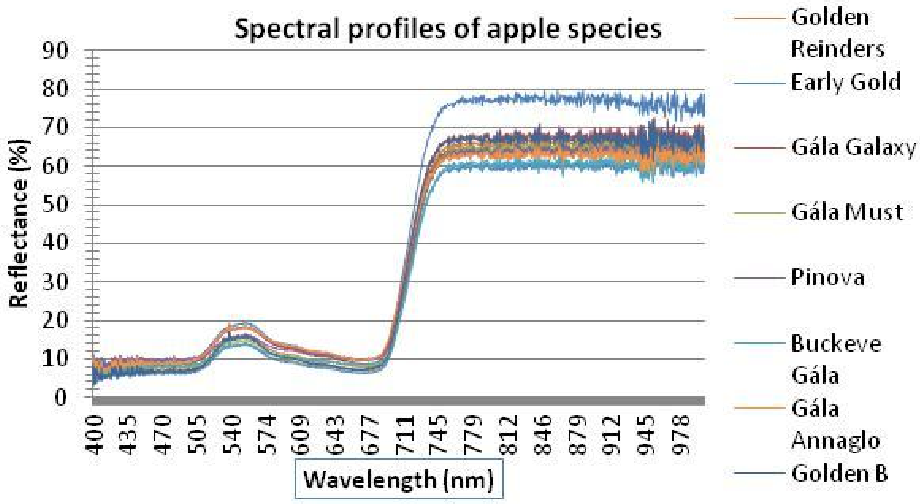

Fig. 2. Spectral profiles of the apple species

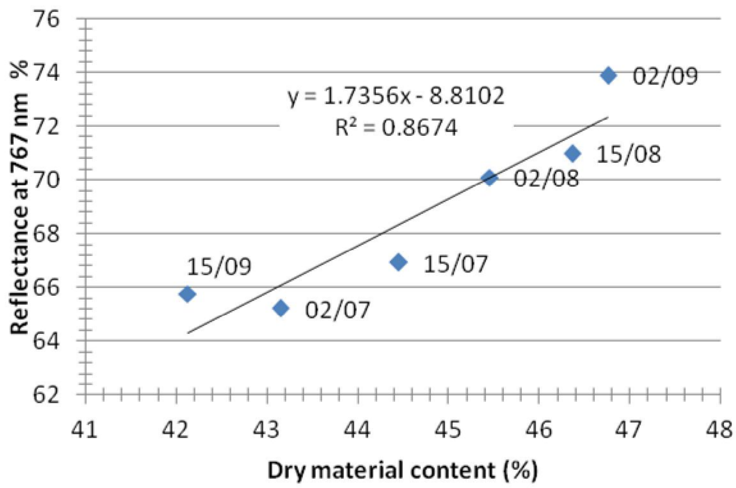

Fig. 3. Correlation between reflectance at a specified spectrum with dry material content

Generally more water in tissues results larger absorbance and less reflectance. But in the 540-575nm interval inverse ratio was found, it is probably due to chlorophyll content, since the characteristics of healthier vegetation is not only observed by more water content, but also the chlorophyll content, which has high reflectance properties at the concerned spectral interval. On the other hand, at NIR spectral range the reflectance increases as the dry material content grows, due to the water content changes and the changes of the internal structure of the leaves (Figure 4). Therefore, in the case of this spectral measurement method NIR spectral interval (750-830) should be used for water content and water stress detection in leaves.

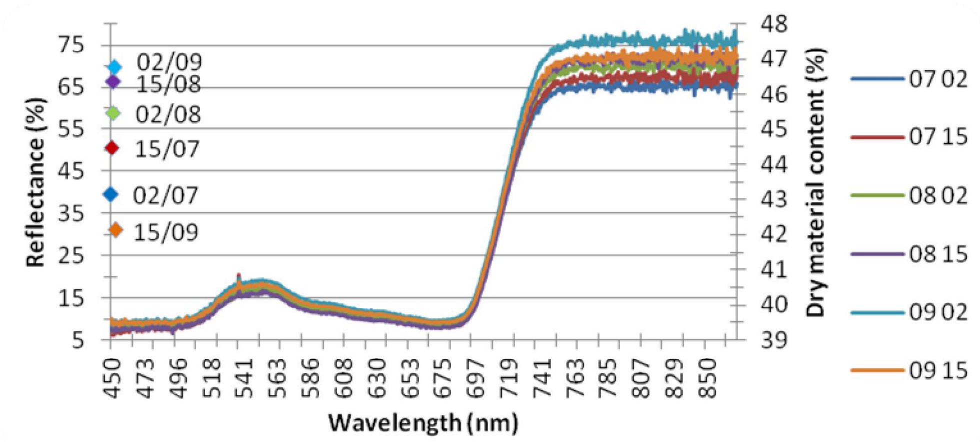

Fig. 4. Spectral properties of Golden Reinders in different phenophase (points represent dry material content)

Examining phonologic phases of the apple trees, the water content of the leaves is permanently decreased. On the other hand, there were some exceptions in the case of several apple species. Small decrease in dry material content was observed in leaves sampled in September. Based on the Tukey variance analysis, these changes were significant. These significant changes were also detected in the case of several wavelength in NIR range as well. (Table 1). This also suggest to use the NIR range (750-830 for water content detection and water stress analysis of trees.

Table 1

Changing of dry material content in the vegetation period based on Tukey variance analysis

Time series	Dry material content (%)	Reflectance at 767 nm
02/07	41.65[a]	63.77[a]
15/07	46.47[b]	67.30[ab]
02/08	46.47[b]	69.57[ab]
15/08	43.54[c]	74.15[b]
02/09	43.18[ac]	69.87[ab]
15/09	41.88[a]	65.29[a]

*no significance differences within values labeled by the same letter (P<0,05)

The reason for small decrease in dry material content is the weather. There were no significant precipitation in July and August before the sampling, but in September 10-15 mm precipitation has fallen, which increased the watercontent of the leaf samples.

Since water stress can cause decrease of chlorophyll pigment decrease in leaves, the detectability of chlorophyll was also measured. In correspondence with several studies, there is strong correlation between relative chlorophyll content measured by SPAD and the absolute chlorophyll content (Figure 5). Thus, this SPAD method is appropriate for decreasing sample numbers for laboratory studies and for saving chemicals and time during our experiment.

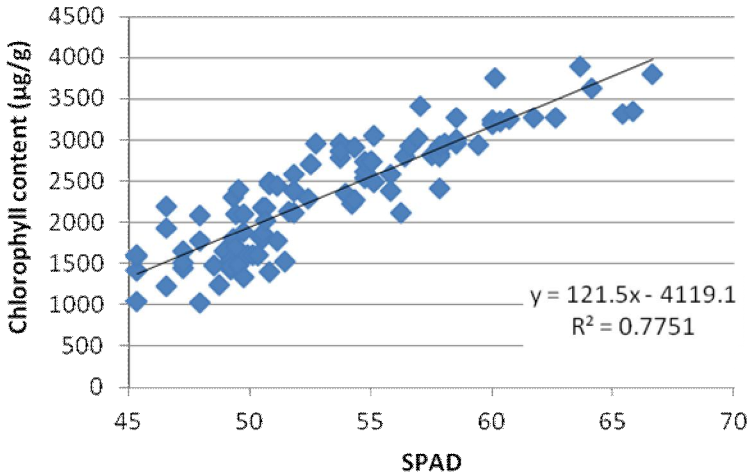

Fig. 5. Correlation between chlorophyll content and SPAD values

In accordance with several studies significant correlation (r~-0.7) can be detected between chlorophyll content and reflectance properties at 520-600 nm and 695-715 nm interval due to the absorbance of chlorophyll.

CONCLUSIONS

The spectral profiles of apple leaves describe properly the spectral characteristics of healthy green vegetation, although spectral filtering is needed for proper examination. Even after filtering, Water Band Index can not be calculated from leaf reflectance data. For water stress detection 750-830 spectral interval in NIR range can be used.

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