EVALUABILITY OF APPLE ORCHARD WATER BALANCE PARAMETERS BASED ON THE SPECTRAL AND THERMOGRAPHIC PARAMETERS OF THE CANOPY

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In Hungary about 100.000 hectares of orchards can be found, from which apple is cultivated on one of the largest areas. The total area of apple and pear orchards is more than 45000 ha. Apple orchards cover about 60% of the total pomiculture in Hungary, although in the last period the production was reduced. The production of marketable horticulture products is difficult without quality horticulture practice, which in many cases is the primary condition of appropriate management and irrigation systems. The data of the Central Statistics Office show that 28% of the apple and pear orchards can be irrigated, but only 21% is irrigated. Since horticulture is a water demanding sector, high quality fruit-production is difficult without proper irrigation. Furthermore in some horticultural farms there is no irrigation applied, or its techniques is improper. There are several experiments going on around the world to develop methods of water management, which draw different technology combination for the water and energy saving water management and irrigation methods. One of the biggest professional challenges of the following years is to develop the water resource management for apple trees. For this the water norm of the trees has to be identified in the different phenological stages, the irrigation turns, and good cultivation practice and the transpiration surface. Hungary has favourable agro ecological potential for apple fruit production, although intensive apple orchards need irrigation to avoid plants from water stress and increase the apple yield security and quality. Modern irrigation system strongly requires proper irrigation scheduling and control (Gonda and Apáti 2011).

THE ROLE OF THE THERMOGRAPHIC PARAMETERS OF THE CANOPY IN EVALUATING THE WATER BALANCE OF THE ORCHARD

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. Combining airborne remote sensing technology and 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. 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. 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. 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 (Burai et al., 2009). In reference to this, searching areas referring to early recognizability 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.

For the examinations, the portable Konica Minolta Soil Plant Analysis Development (SPAD) type 502 dual-band manual instrument can be used that can be used easily, it is relatively cheap and enables instant, direct measurement without damaging the leaves. Another one of its advantages is its quite low weight since it is less than 300 g even with the batteries. Its principle of operation is based on that chlorophyll molecules can absorb different amounts of light with different wavelengths, the amount of which is closely related to the chlorophyll content of the leaves. It absorbs the most light at blue and red wavelengths, while light absorption is low in the green and yellow spectrum, and is practically null at infrared wavelengths. The measuring instrument uses red light, the absorption of which is not influenced by the carotene content of the leaf. There are 2 diodes (LEDs) in the instrument: one is red, 650 nm, and the other is infrared with a peak of 940 nm. The two types of light alternatively go through the leaf blade with equal strength, a part of which is reflected, another absorbed by the leaf, while the remaining part goes through the leaf. Chlorophyll only absorbs red light but no infrared. Passing light is sensed by a silicon photodiode and by transforming it to analogue electric signal, the instrument forms it to a number. Therefore this value is determined by the light transmittance of the leaf tissue at the abovementioned wavelengths. The instrument calculates the SPAD-value lacking a unit of measurement – ranging from 0 to values above 100 – from the difference of the relative optic density of red and infrared wavelengths. The more red light is absorbed by the leaf of the plant, the higher is its chlorophyll content. The measuring (illuminated) area: 2 x 3 mm, which is quite small, and the veins, the thickness of the leaves (max. 1,2 mm) and their water content can influence the resulting value to a lesser extent, therefore it is worth to do more measurements on the same leaf. The instrument can be used in the temperature range of 0-50°C with a maximum humidity of 85% (Terek 2012).

By making contact between the two clip-on ends of the instrument – with the leaf between them –, it almost instantly displays the measured value on the screen, therefore abnormalities can be instantly filtered out and the measurement can be repeated. The resulting SPAD-values correlate positively to the real chlorophyll content, so they provide quite a correct estimation, therefore they provide an opportunity to substitute excessively time- and energy-consuming chlorophyll measurement with acetone.

For the objective result some vegetation indices are available to detecting physiological changes during the life of plant or fruits, or after the storage, respectively. The leaf chlorophyll content is closely related to plant stress and senescence (Merzlyak et al. 1999). Due to the senescent of leaves the chlorophyll content is deceased. One of the oldest, most well known and most frequently used vegetation index is the Normalized Difference Vegetation Index (NDVI), which use of the highest absorption and reflectance regions of chlorophyll make it robust over a wide range of conditions. NDVI is a measurement value without a dimension for the activity and state of an area based on that the metabolic intensity of the vegetation influences spectral properties. It can be specified from satellite or hyperspectral images. Its index values can be calculated from the reflectance values of pixels with different wavelength ranges, because the reflectance of vegetation shows significant differences in the visible red (RED) and close infrared (NIR) spectra.

It is calculated by the following formula:

$$\mathbf{NDVI} = \frac{\mathbf{NIR - RED}}{\mathbf{NIR + RED}}$$

where: NDVI: vegetation index

NIR: the intensity of reflected light in the near infrared spectrum

RED: the intensity of reflected light in the visible red spectrum

This quotient is directly proportional to the chlorophyll content of the vegetation. We always have to get a result between -1 and +1. Vegetation index is widely used in agriculture, but it has applications in forestry, urban planning and other areas.

The Simple Ratio (SR) index is another old and well known vegetation index, which is similar to the NDVI. In case of very high spectral resolution reflectance data, such as from hyperspectral sensors, could be used the Red Edge Normalized Difference Vegetation Index ($NDVI_{705}$) and the Modified Red Edge Simple Ratio (mSR_{705}) indices. These indexes are more sophisticated measures of general quantity and vigor of green vegetation than the broadband greenness vegetation indexes. A third greenness vegetation index is the Modified Red Edge Normalized Difference Vegetation Index ($mNDVI_{705}$), which incorporated a correction for leaf specular reflection. These vegetation indices differ from the NDVI by using bands along the red edge, instead of the main absorption and reflectance peaks.

The plant senescent and fruit storage injuries could be investigated by several indices as well. The Plant Senescence Reflectance Index (PSRI) is designed to maximize the sensitivity of the index to the ratio of bulk carotenoids (for example, alpha-carotene and beta-carotene) to chlorophyll (*Merzlyak* et al. 1999). The Browning Reflectance Index could provide information about senescent of leaves and/ or ripening of fruits too.

Several other parameters were examined based on the spectra. The color, maturity and health status was analysed in the yellow –red (570-730) wavelength interval, where a significant sigmoid growth of reflectance appears. Differences between relative water content of the leaves can also be assessed in the near infrared (NIR) zone between 900-970 nm by the Water Band Index (WBI) based on airborne hyper spectral data. WBI is a ratio sensitive to the water content of the foliage that is a result of the following formula: WBI= 900/ 970. As the water content of the foliage increases, so does the absorption of light in the 970 nm spectrum compared to the 900 nm one. At our examinations in the apple orchard, it was also the 900 nm channel being a sensitive water indicator, but the 930-940 nm spectrum should be used in the denominator, because the reflectance curve showed a minimum there in contrast with the 970 nm channel cited in the literature. Based on this, the reflectance values of WBI= δ 886/ δ 937 channels provide a more correct result in the case of pomes. Beside the water supply of the examined specimens, mapping the areas of a plantation with different water supply by remote sensing methods can be the based on reflectance spectra.

APPLICATION OF THERMOGRAPHIC CAMERA IN APPLE ORCHARDS

Since canopy temperature acts as a good indicator of plant water status, infrared thermography is considered for the identification of plant water stress and is also used as a tool for irrigation scheduling method. The basic idea of its operation is that – because of optimal evaporation – the leaf temperature of trees with good water supply is lower compared to those short of water, therefore the cooling effect of evaporation can show up only to a lesser extent. If plant water stress increases, transpiration decreases and plant temperature may exceed air temperature. On the other hand, non-stressed plants will have canopy temperatures less than air temperature, particularly when vapour pressure deficit (VPD) is not greater than 4 kPa. The crop water stress index (CWSI) relates canopy–air temperature difference to net radiation, wind speed and vapour pressure deficit. However, a surrogate measure is calculable from the temperatures of the canopy and reference leaf surfaces corresponding to fully transpiring and non-transpiring canopies (Jones et al. 2002). Thus, by monitoring plant canopy temperature and the temperatures of wet and dry leaves, it is possible to estimate the underlying plant water stress status and therefore, intelligently control the related irrigation process. We can make an image of the surface temperature of the canopy with a thermographic camera (Figure 1).

In the outer steel case of the camera, there is a microblometer sensor with 7800 elements (in a 320x240 arrangement) that does not need cooling. Its sensibility is an average of 0,05 °C. Its range of measurement is between -20 and 120 °C, but its optimal working temperature is between -25 and 60 °C. We can analyse the images with IRPlayer software which is an own development of Hexium Ltd. The software makes it possible to export temperature values belonging to the pixels to an external csv file. The resulting file stores the values of each pixel in a matrix-like structure. With the help of this software, it is possible to save the image and the thermal scale, too. For the simpler use of the pictures and the colour intensity, we may use a black and white image. In the IRPlayer software, the thermal range that characterises the temperature of the surface best (Figure 2).

Figure 1: HEXIUM PYROLATER-12 thermographic camera and its image in an orchard

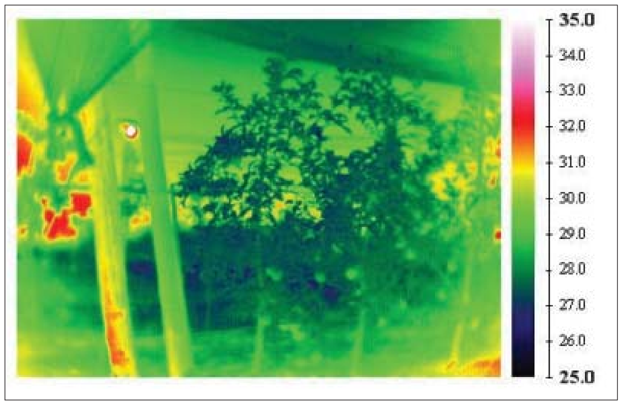

Figure 2: The thermographic image of the apple orchard

Based on thermographic image, the temperature parameters of apple yield, leaf, trunks were investigated. The air temperature was measured by analogous thermometers in shade and reached its minimum at dawn. The result suggests that parallel to the air temperature, the temperature of the examined apple tree parameters also increased. Furthermore, the leaf temperature exceeded the air temperature, which shows water deficiency and the inadequate transpiration (Figure 3).

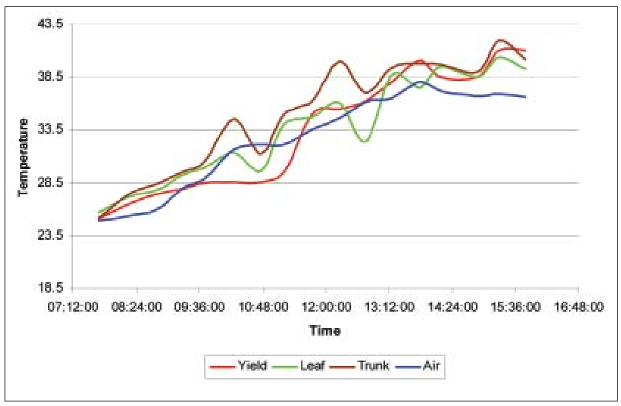

Figure 3: Temperature changes (°C) in apple orchard

As a consequence of this, increased water stress can be observed in the orchard, because the intensity of photosynthesis depends on the water supply of the plant. In the absence of irrigation, stomata close in noon time due to water shortage, therefore there is a minimum of photosynthesis intensity. This does not show up in irrigated areas with sufficient water supply.

A key procedure for the evaluation of crop water stress from plant canopy temperature was to calculate CWSI based on the data collected from IR thermography systems. The CWSI described by (Jones et al., 2002) is of the following generic form:

$$CWSI = \frac{T_c - T_w}{T_d - T_w}$$

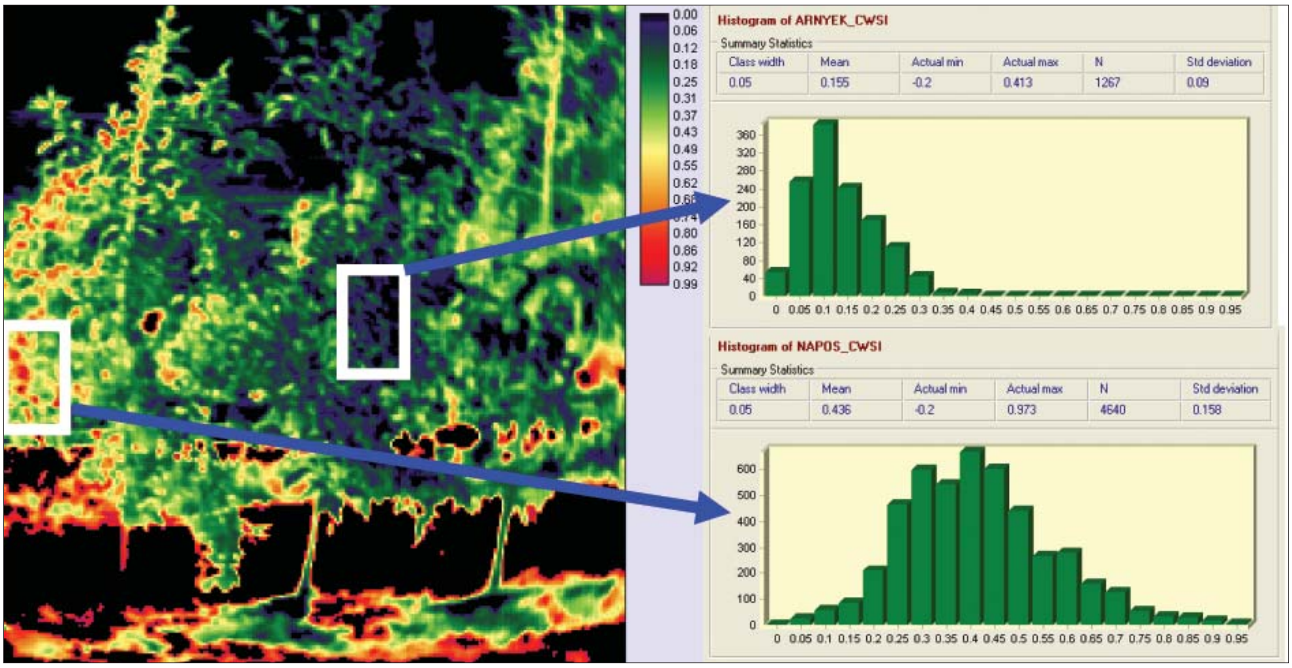

Figure 4.: CWSI of the apple trees on sunlite and shade side

where Td and Tw represent the reference temperatures for dry (nontranspiring) and wet (fully transpiring) leaf surfaces respectively. T_c is the temperature of the transpiring surface, i.e., the actual measured temperature of all sunlit leaves to represent the sunlit portion of the canopy. Although alternative methods for estimating reference temperatures may be found, reference leaves, which are artificially treated real leaves with known conductance to water vapour, can be physically embedded in the scene and so the reference temperatures T_d and T_w can be estimated from the leaf temperature distribution. In this study the reference temperatures T_d and T_w can be estimated from the leaf temperature and air distribution. Before the CWSI calculation masking was made in order to eliminate the background and keep only the apple trees on the infra red image. The image processing was made in IR Player, Surfer9 and the CWSI analysis were carried out in Idrisi Tajga software environment. Based on CWSI image, those parts of the canopy were easily eliminated, where the increased water stress occurred (Figure 4).

This due to water deficiency, caused by the lack of precipitation and irrigation, stomatal closure can occur thus, according to several studies (Pethő 1996) the photosynthesis is blocked and reach its minimum. Not only the transpiration is blocked but also the CO_2 uptake, therefore reactive hidroxil radicals are produced which are harmful for the chloroplasts and cell membranes, which eventually causes the water stress symptoms in plants.

Based on CWSI image, it can be stated, that irrigation was urgently needed for the orchard. This result is also confirmed by soil water monitoring survey, which was carried out by tensiometers. According these results, irrigation should have been started 2 weeks before.

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