Proximal sensing applications to study the spectral response of raspberry plants to different light conditions

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Abstract
One of the biggest challenges of raspberry production in Hungary nowadays is climate change. Periods of extremely high temperature and atmospheric drought can detain fruit growth and reduce quality. Dedicated plant breeding alone is not enough to fight the climate change. Different physical protection can however mitigate several related stress-factors. One of the most decisive limiting factors is probably the excessive solar radiation. Visual signs of heat stress, sunburn are often registered during the summer periods induced by excessive heat and direct radiation causing decreasing photosynthetic activity of plants. The domestic raspberry production needs technological change. There are artificial and natural ways to follow. Greenhouses or poly-tunnel solutions are quick to deploy and offering an immediate solution. Agro-forestry systems need several years to grow and support the farmers so they provide a middle- and long-term solution. The authors would like to introduce their observations in an experimental plantation of different raspberry varieties, where besides the monitoring of elementary biological indicators a wide range of environmental sensors (temperature, humidity, solar irradiation) and proximal sensing equipment were used to identify differences generated by the applied production technologies.
Keywords: excessive solar radiation, raspberry plantation, proximal sensing

Introduction

There has been more and more indication of climate change related stress factors in raspberry plantations all around Hungary in the last couple of years. Farmers regularly experience reduction in plant growth, leaf area, yield and fruit quality. Visual signs of heat stress, sunburn are often registered during the summer periods induced by excessive heat and direct radiation causing decreasing photosynthetic activity of plants. Dedicated plant breeding programs has been started to mitigate the effects of climate change (Dénes, 2016) but these programs need long time. Fighting alone by using biological ways is not enough. An immediate action is required to save the raspberry production. A physical protection against excessive direct radiation can be considered as the only way to restore the stability and quality of production on short term. Nevertheless, returning the site of raspberry production to the forests (where the species is originated from) or agroforestry systems (Nagy, 2017) can be also considered as a solution on middle and long term. Combining solar panels with agriculture (Hanley, 2017, Hajdú, 2018) in this particular place can offer an even more reasonable way to solve the question of excessive radiation (Figure 1).

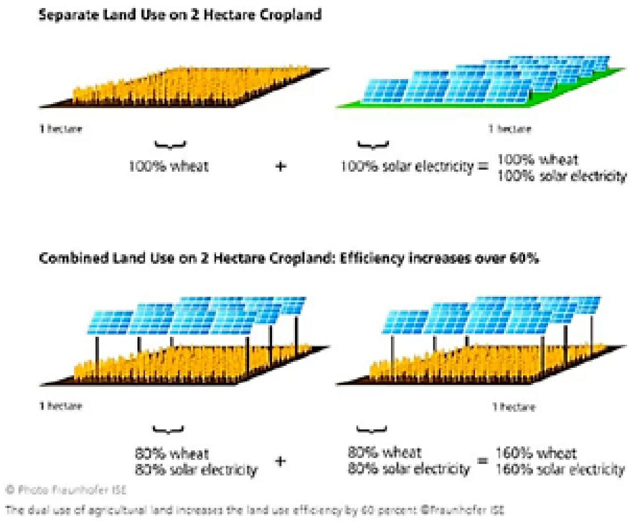

Figure 1: The theory of combined land use (Hanley, 2017, Hajdú, 2018)

An accurately adjusted portion of radiation would be transferred to electricity while the rest can be used by the protected plantation below. In this case the shading system would produce energy which would possibly offer a more sustainable way of fighting against the effects of climate change (Deákvári, 2018) and energy scarcity. Beside the reduction of direct radiation various shading solutions and applied materials are expected to change the spectral characteristic of incident light and so the light utilisation of plants. In order to find a reasonable solution to protect the plants and increase the stability of the production a raspberry plantation with different varieties was established. A sun protective shade tunnel system was erected to create a test site at NARIC - Fruitculture Research Institute (FRI), Fruit Culture Research and Development Institute of Fertőd, Hungary. It provides opportunity to measure and evaluate relevant biological and physical parameters playing an important role in berry production (Keller et al., 2018). In order to create the basis of a comprehensive study where artificial and natural ways of protection can be monitored and compared a the experiment was expanded to an agroforestry system.

Beside the conventional vegetative and productive indicators of plant growth environmental parameters like soil and ambient temperature [C°], humidity [%], PYR and PAR radiation [nm] were measured with in-situ sensors. To measure the spectral conditions (Judd et al., 1964) under the shade nets and the spectral response and features of plants with proximal sensing a portable spectroradimeter and a snapshot hyperspectral camera were used. Portable spectroradiometers can widely be used both in field and laboratory. It is adequate to carry out independent, fast and precise evaluations in an economic way. The VNIR device extends the range of the detectable visible light (Lágymányosi and Szabó, 2009) to NIR (near infrared) and the SWIR (shortwave infrared) region and covers the spectral range of 350 to 2500 [nm] (Csorba et. al, 2014). These spectrometers have successfully mastered several applications; however scanning (Fenyvesi 2008, Milics et al., 2008, Milics et al., 2010, Fekete et al., 2016) is facing some limitations when the test object or/and camera are randomly or rapidly moving in time and space. To eliminate all these limitations snapshot hyperspectral imaging or spectral frame camera technique (Jung et. al., 2017a) can be successfully applied. In principle, it is capturing the entire hyperspectral image during a single integration time (one shot takes about 1 ms). In agricultural field and close-field applications weight and speed are of high importance (Jung et al. 2017b).

Materials and Methods

Experimental plantation (Figure 2) of three different raspberry varieties was set in two repetitions: covered and uncovered versions. Each cover has characteristic interaction with light which is expected to generate different environmental conditions and also differences in plant growth and fruit quality. In-situ environment monitoring was carried out by light, temperature and humidity sensors in different treatments (Figure 3 and Figure 4).

Izolátorhálós									
8, 7, 6, 5, 4, 3, 2, 1	Julcsi	Fertődi zamatos	Eszterházai kétszertermő	Fertődi zamatos	Eszterházai kétszertermő	Julcsi	Fertődi narancs	Julcsi	Fertődi zamatos
	1. sor	2. sor	3. sor	1. sor	2. sor	3. sor	1. sor	2. sor	3. sor
	1. sátor			2. sátor			3. sátor		

Szabadföldi									
8, 7, 6, 5, 4, 3, 2, 1	Julcsi	Fertődi zamatos	Eszterházai kétszertermő	Fertődi zamatos	Eszterházai kétszertermő	Julcsi	Fertődi narancs	Julcsi	Fertődi zamatos
	1. sor	2. sor	3. sor	1. sor	2. sor	3. sor	1. sor	2. sor	3. sor
	1. sátor			2. sátor			3. sátor		

Figure 2: Tunnels with different cover materials (shade nets)

Figure 3: PYR Apogee SP-110 360-1120 [nm] and PAR Apogee SQ-100 380-720 [nm]

Figure 4: Temperature sensors at: - 0,15 [m], 0 [m], 1,0 [m], 1,8 [m].

Portable spectral field measurements were carried out in the control area and under two different types of tunnels. Data acquisition was made by using ASD FieldSpec 3 MAX portable spectroradiometer (350-2500 [nm]) with Plant Probe sensor and Cubert snapshot spectral camera (400-1000 [nm]) on randomly selected leafs (Figure 5 and 6). The same reference panel was used as a standard surface reflecting 95 % of all incident radiation for both acquisition methods.

Figure 5: Operation principle of ASD FieldSpec 3 MAX and Cubert snapshot camera

Figure 6: ASD FieldSpec 3 MAX with PlanProbe sensor head and a Cubert snapshot camera

In order to compare the light utilization efficiency, the water and nitrogen management of plants under various shade nets contact measurements was used to calculate vegetation indices such as photochemical reflectance index (PRI), water index (WBI) and normalized nitrogen index (NDNI) with the following equations:

$$PRI = \frac{\rho_{531} - \rho_{570}}{\rho_{531} + \rho_{570}} \quad WBI = \frac{\rho_{970}}{\rho_{900}} \quad NDNI = \frac{\log(\frac{1}{\rho_{1510}}) - \log(\frac{1}{\rho_{1680}})}{\log(\frac{1}{\rho_{1510}}) - \log(\frac{1}{\rho_{1680}})}$$

The raspberry experiment will be expanded to an agro-forestry plantation which was also created at NARIC - Fruitculture Research Institute (FRI), Fruit Culture Research and Development Institute of Fertőd, Hungary, near to the Sun protective shade tunnel system (Figure 7).

Figure 7: The agro-forestry plantation.

Results

In-situ environment sensors were continuously collecting the ambient parameters. Datasets were stored in internal memories. Data were downloaded on a regular basis and processed to plot the variation of the parameter within days, weeks and months throughout the vegetation period (Kollányi and Szalay, 2016). Figure 8 and Figure 9 illustrates well the differences between the treatments in case of PYR radiation and soil temperature. These datasets very well represent the difference between environmental conditions between the shading nets and the natural radiation as well.

The processed contact spectral measurement dataset revealed a tendency of differences in case of photochemical reflectance index (PRI). Based on the dataset the light utilisation efficiency of all varieties under shade nets were higher than in the control plantation.

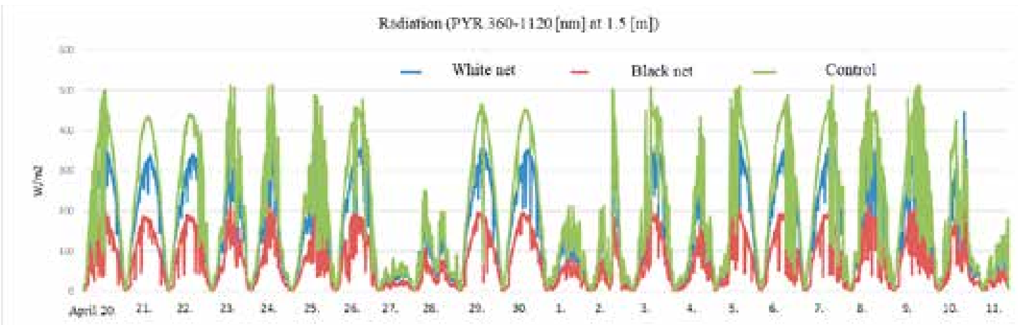

Figure 8: Distribution of PYR radiation.

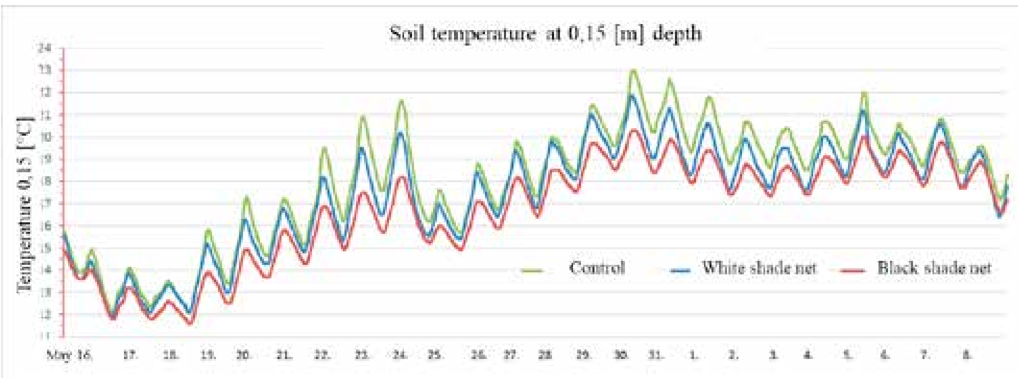

Figure 9: Distribution of soil temperature.

Water index (WBI) and normalized nitrogen index (NDNI) did not show differences between treatments. It means the soil preparation; nutrient supply and irrigation assure the favourable homogeneity of the plantation and the only variable between treatments really is the difference in illumination. The images acquired with snapshot camera were used to evaluate the shade nets and open sky from below to describe the spectral distribution of the incident light. On the other hand, vegetation survey was performed to visualize reflective features of the vegetation and also the heterogeneity arising within plants (Figure 10.).

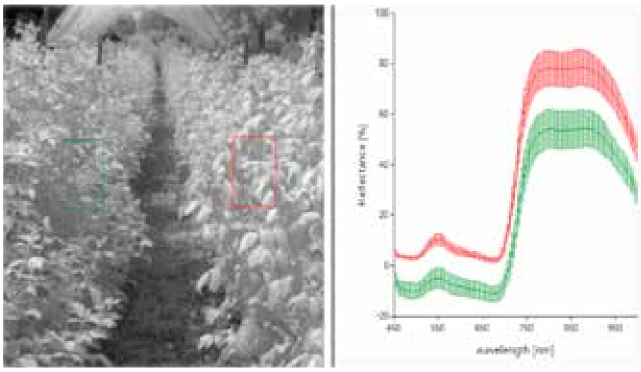

Figure 10: Heterogeneity arising from the illumination direction (light touches – on the right and shadowy place – on the left)

Differences between ratios of significant ranges playing important role in vegetation monitoring to indicate alteration of plant condition (Figure 11.).

Generally true that the main indicators of different efficiency of production technologies are yield and fruit quality. Within the frame of the research correlations between shade nets and fruit size was observed. Julcsi reacted positively to the white coloured shade net in two consecutive years with extra 72 [%] (2016) and 24 [%] of yield. Eszterházai kétszertermő reacted with extra 140 [%] (2016) and 104 [%] of yield moreover with extra fruit size 4,6 [%] (2016) and 36,69 [%] (2017). Fertődi zamatos did not show such a significant reaction to the treatment.

Conclusions

A portable spectroradiometer and a snapshot hyperspectral camera with more than 100 spectral channels were used to spectrally map a raspberry plantation under different type of shade nets. It was also a purpose to test and document the usability, flexibility of such techniques in collecting spectro-phenological parameters in a hand-held way. An in-situ ambient monitoring system was also set up to collect temperature, humidity and radiation data. Spectral techniques provided opportunity to reveal such differences in natural light conditions that are usually not detected by traditional weather stations and make possible to study the correlation between light condition and plant growth in a more complex way.

The results show significant differences between plantations with or without shade net cover. Measured ambient parameters and spectral analysis of the vegetation revealed differences in plant condition and indicated the effect of shade nets and also the differences between the two experimental shade net materials. Shade nets can increase the yield and also increase the average berry size but the reaction to shade nets seems to be variety-specific. Yield reacted very positively to white shade nets in case of Eszterházai kétszertermő and Julcsi varieties, in two consecutive years. Fruit size reacted positively in 2017. In case of Fertődi zamatos variety significant positive effect of shade materials was not confirmed. Variety-specific shade net-based production technology can offer a solution to improve yield, quality and production stability of raspberry. The tunnel system can be quickly deployed so it offers an immediate action to mitigate the effects of climate changes. It can also serve as an intermediate step towards agroforestry systems or remain a complementary technique with options to be used as spectral filters adjusted to plant needs or physical barriers for pests or to create a microclimate. Although the first synthesises already show useful correlations for the practice further crop years and additional measurements, analyses are necessary to identify the best production practice.

In the coming years the authors will study the study the berry production in the agro-forestry system and under shade nets in parallel. The alternative ways of protected production technologies will be compared. Beyond the standalone positive effects of artificial and natural protection ways their joint utilization in a complex system may reveal further synergism in the practice.

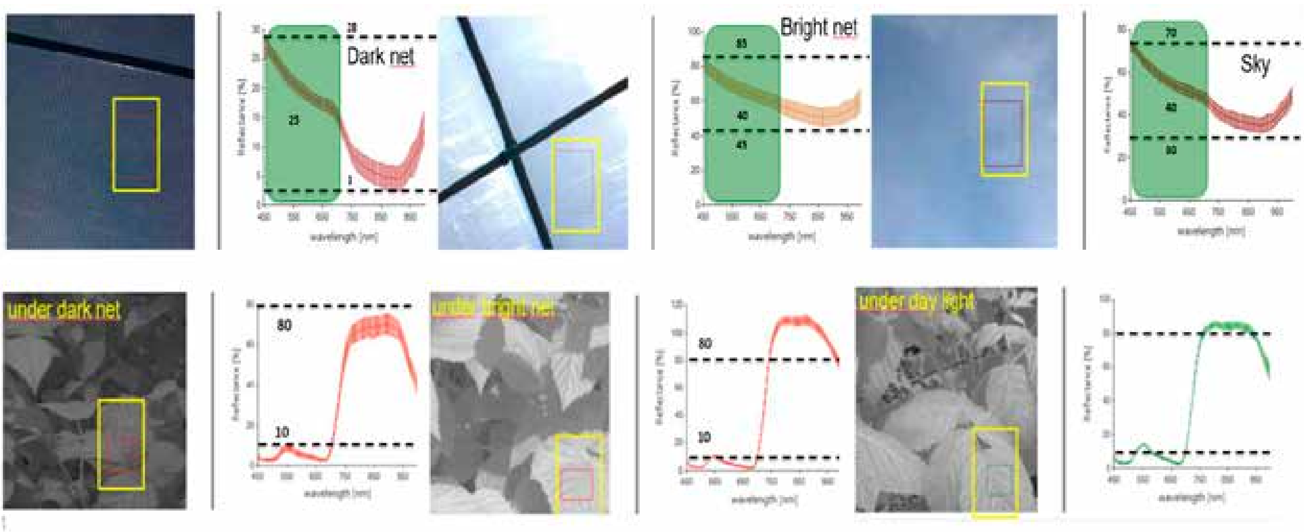

Figure 11: Hyperspectral images describing the incident and reflected radiation in the VIS and NIR region.

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