Water Stress Detection in Rooftop-grown Bush Beans Using Close Range Hyperspectral Remote Sensing

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Introduction and Objective

The frequency of droughts is expected to increase with climate change (Xu et al., 2019) and have a material impact on the agricultural industry and the demand for fresh water. As such, our ability to detect water stress in crops in a timely manner is critical for crop preservation, efficient water management and maintenance of the global food supply.

Remote sensing offers a non-invasive and timely analysis of agricultural vegetation compared to most traditional methods (Díaz-Varela et al., 2015). Using tools such as spectroradiometer (ASD in this study) allows detection of changes in reflectance from a leaf and construction of spectral reflectance curves across a much wider range of wavelength (hyperspectral) compared to other methods. Each plant has its own unique spectral curve (i.e., spectral signature) and the analysis of changes in these curves through time (both visual and via vegetation indices) are known to reveal such problems as nutritional deficiencies (Moharana & Dutta, 2016), diseases (Martins et al., 2017) and water stress (Zhang & Zhou, 2019). Given the high cost of spectroradiometers, a relatively small number of studies have been conducted on the subject to date, and especially on the impact of intercropping and ground cover facilitation treatments (e.g., sedum vs no sedum) on water stress, which are covered in this study.

Lastly, green roofs take advantage of the stormwater and hence require less fresh water, reduce building energy costs, and alleviate the heat island effect. Furthermore, rooftop studies such as these are necessary in the development of technologies that could be deployed on satellites capable of surveying substantially larger agricultural landscapes than a handheld spectroradiometer used in this study.

Objective: Identify water-stress sensitive wavelength regions and vegetation indices using hyperspectral data in a rooftop experiment.

Methodology

Experimental Design:

The study was conducted on a Highland Hall rooftop at UTSC led by Prof. Isaac's team during July and August 2021.

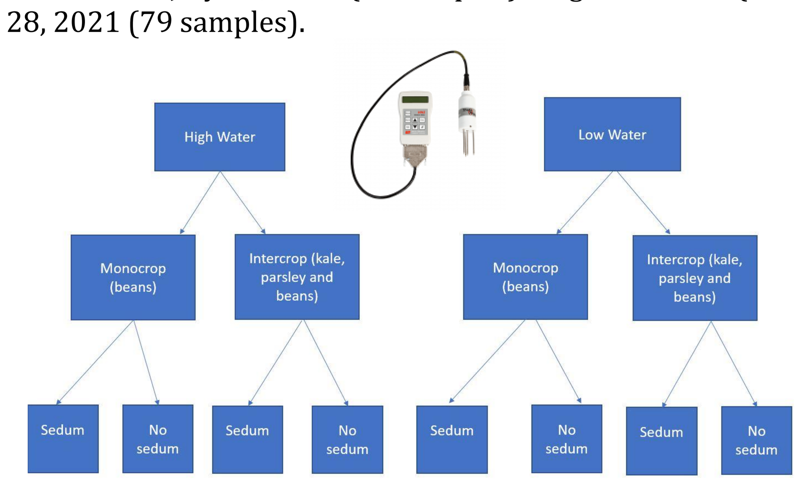
Two water stress treatments were implemented:

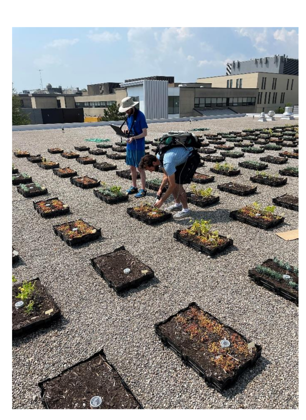
- High (**H**): soil moisture target of above 30%, and
- Low (**L**): soil moisture target of 12% - 30%.

In addition, the following four treatments were also conducted:

- **Sedum** vs **No Sedum**: *S. album* and *S. sexangulare* covered the ground of some modules while not others.
- **Monocrop** vs **Intercrop**: some modules had only bush beans (*Phaseolus vulgaris*) growing (i.e., Monocrop), while in others – in addition to beans had Russian red kale (*Brassica napus va. pabularia*) and Italian parsley (*Petroselinum crispum*) also growing (i.e., Intercrop).

Out of the total number of 288 modules only a sample of each treatment was collected on July 26, 2021 (25 samples), August 3, 2021 (140 samples), and August 28, 2021 (79 samples).





Hyperspectral data were collected using an ASD FieldSpec 4 (Malvern Panalytical), which captures reflectance from 350 nm to 2500 nm with an interval of 1nm. Leaf clip was used to measure bush bean leaves.

Soil moisture was measured using a delta-T HH2 moisture meter with a ML3 sensor, which is a simple probe inserted into the module to retrieve soil moisture readings, with accuracy of +- 3 % moisture.

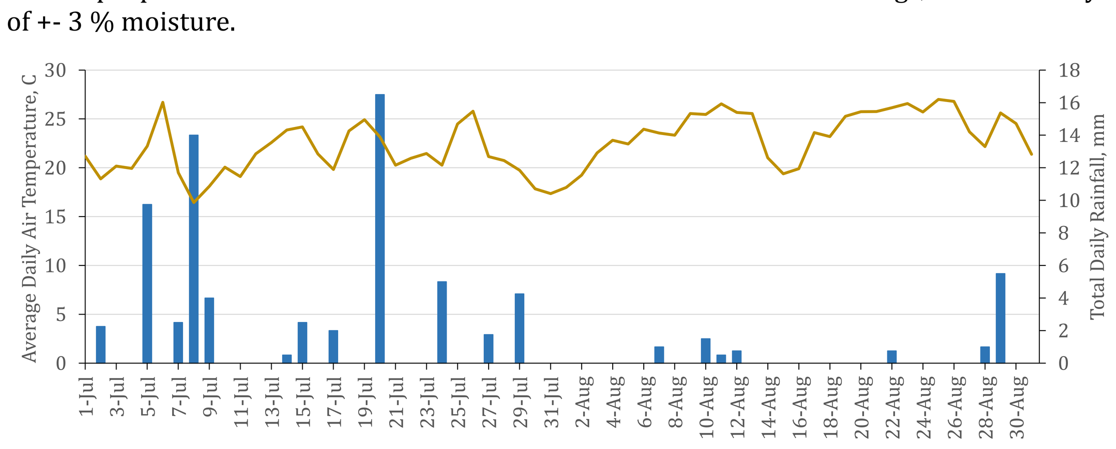
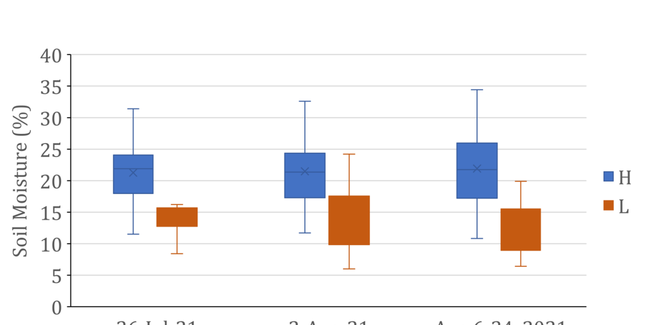


Figure 1. Air Temperature and Rainfall during July and August 2021 at UTSC.



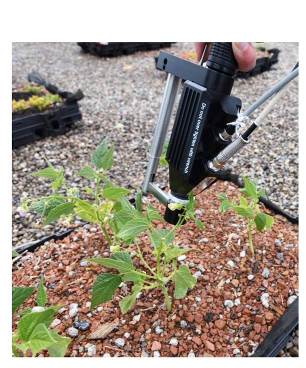


***Figure 2.** Soil Moisture in the rooftop modules used in this study during each period.*

Vegetation Index	Formula	References
Green chlorophyll index (CI_green)	(R750/R550) – 1	Gitelson et al., 2005
Red edge normalized ratio (NR_red edge)	(R750 – R710)/(R750 + R710)	Gitelson & Merzlyak, 1996
Simple ratio water index (SRWI)	R860/R1240	Zarco-Tejada & Ustin, 2001
Water index (WI)	R900/R970	Peñuelas 1997
Normalized difference vegetation index (NDVI)	(R800 - R680)/(R800 + R680)	Rouse et al., 1974
My Index	R700/R410	

***Table 1.** Vegetation Indices used in this study.*

Conclusions and Future Directions

The wavelength in the visible and red-edge ranges of the spectrum were the most sensitive regions to water stress in an experiment that focused on bush beans grown on a rooftop at UTSC during July and August 2021. This study also identified 700 nm wavelength as the most responsive to water stress, along with CI_green and NR_red_edge vegetation indices.

Given that there were many inconsistencies in the response to water stress across the four treatments identified here, a longer-term study across multiple summers is recommended to confirm (or dispute) the findings of this study. In fact, during the summer of 2022 new data has been collected, which should allow validation of these results for at least one more growing season.

Future research can also investigate Intercrop treatments more closely to confirm that early in the growing season competition from other species could be a more important factor than water stress.

Lastly, we believe the index identified in this study - R700/R410 could be worth further investigation in hopes to provide insights about plant health that are not addressed by previously studied indices such as CI_green and NR_red_edge.

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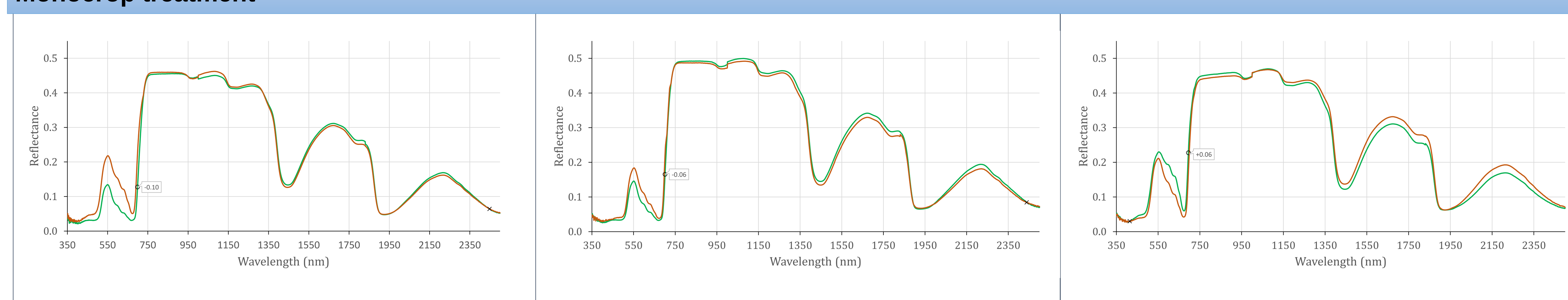
- Prof. Marney Isaac team: especially Adriano Roberto and Chelsea Aristone

Results: Hyperspectral Curves

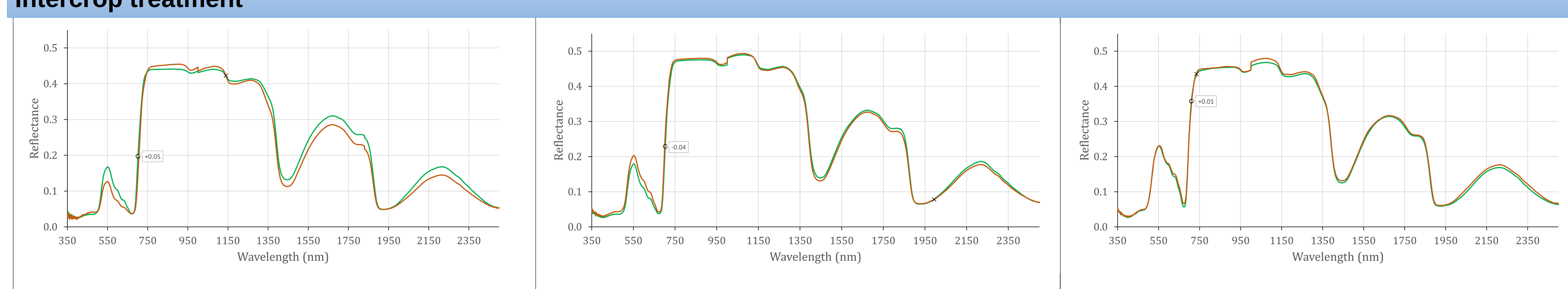
H L ○ Largest difference between H and L ✕ Smallest difference between H and L

July 26, 2021 | August 3, 2021 | August 28, 2021

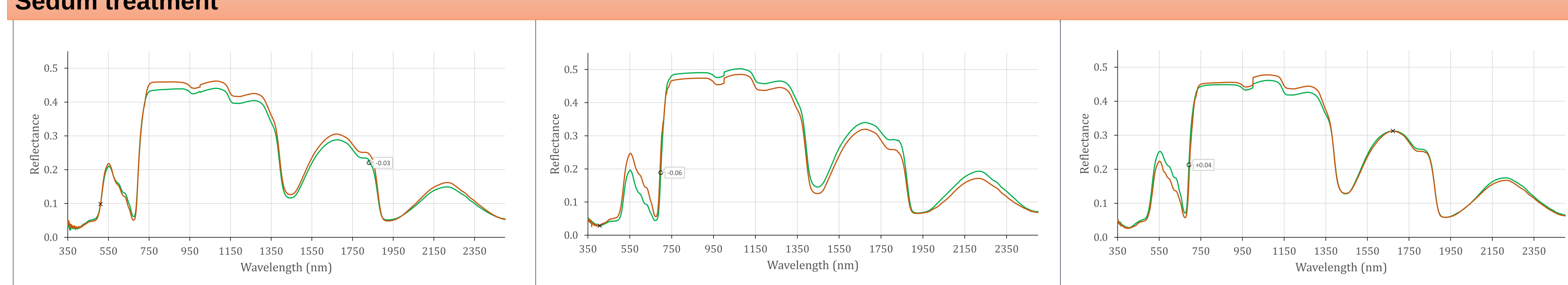
Monocrop treatment



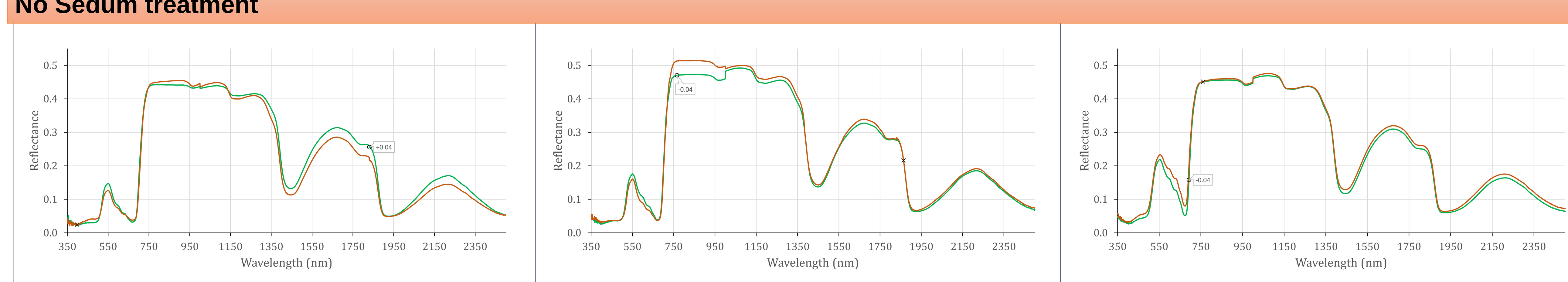
Intercrop treatment



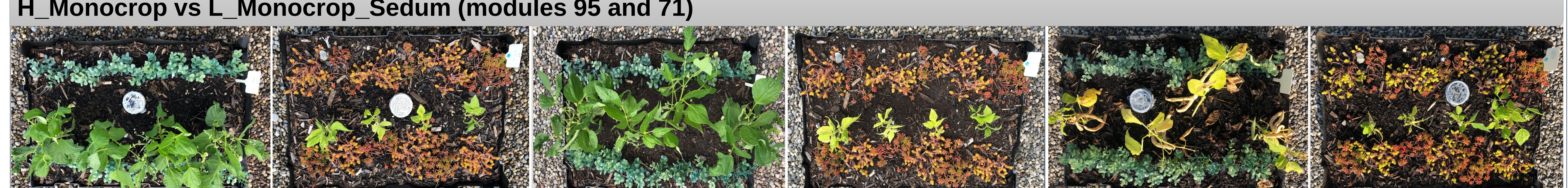
Sedum treatment



No Sedum treatment



H_Monocrop vs L_Monocrop_Sedum (modules 95 and 71)



H_Intercrop_No Sedum vs L_Intercrop_No Sedum (modules 35 and 155)

H_Sedum vs L_Sedum (modules 122 and 71)

Results: Vegetation Indices and Reflectance at 700 nm

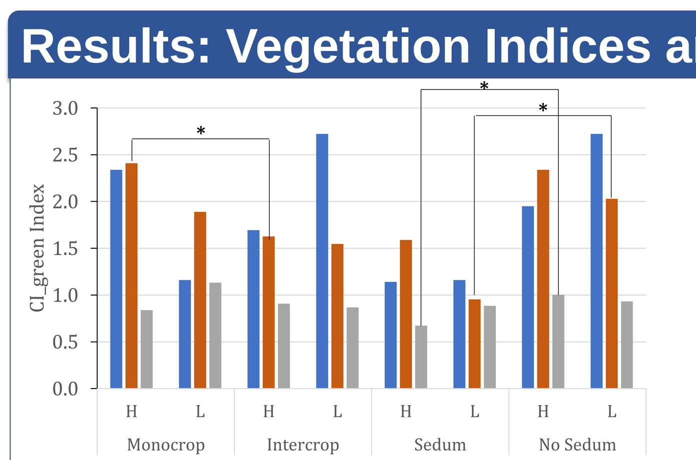


Figure 3. CI_green Index.

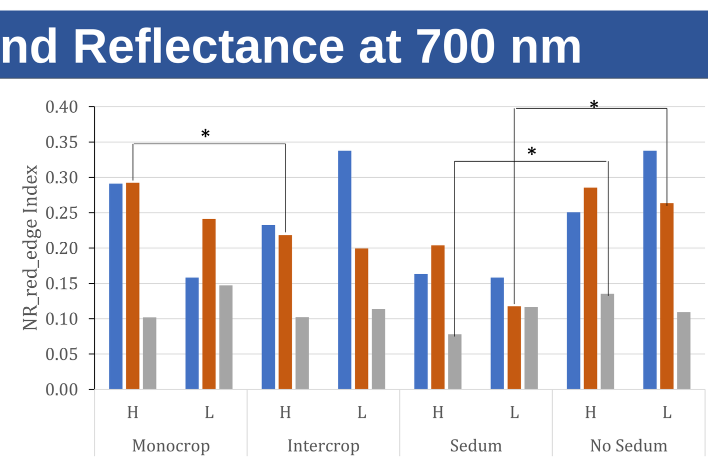


Figure 4. NR_red_edge Index.

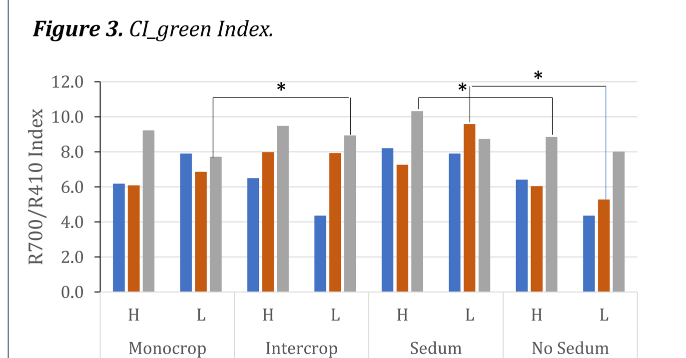


Figure 5. My_Index - R700/R410.

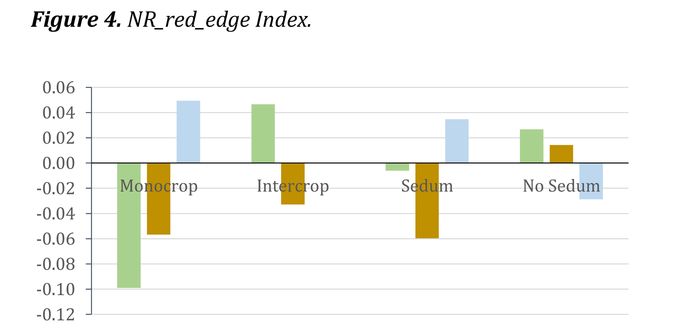
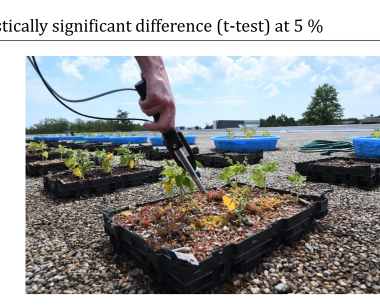
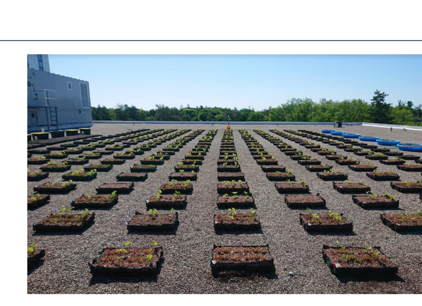


Figure 6. Difference in reflectance between H and L at 700nm.

* statistically significant difference (t-test) at 5 %





Discussion

1. The results of this study suggest that water stress can be detected in bush beans growing on a rooftop by investigating the changes in the reflectance for the wavelengths in the red-edge part of the spectrum (700 – 750 nm) and in the visible part of the spectrum (350 – 700 nm), which is in line with El-Hendawy et al. (2017) and Sun et al. (2019) results.
2. The largest difference in reflectance between H and L treatments was found in the red-edge part of the spectral curve, particularly at a wavelength of 700 nm. In general, as shown in Figure 6, water-stressed treatments (L) had higher reflectance at 700 nm than H treatments early (July 26) and mid-season (August 3) resulting in the negative difference between H and L, with one notable exception - the Intercrop treatment. Treatments without Sedum also show the reverse trend early in the season, although their differences are lower compared to Intercrop. At the end of the growing season (August 28), this trend seems to have reversed. Given that there is an overlap in modules used in the four treatments presented here, a more in depth analysis is necessary to confirm these results.
3. Early in the growing season the presence of other species in the modules (Intercrop treatment) was more detrimental to the growth of bush beans than water stress, suggesting that perhaps competition for nutrients from other species was more important than water deficit. This is particularly evident in the visible range of the hyperspectral curve (550 to 700 nm) with H treatments having a weaker chlorophyll absorption than L treatments and lower reflectance in the near infrared region (750 – 950 nm).
4. Lastly, this study has reviewed the potential utility of six indices, and confirmed Zhang & Zhou (2019) finding that CI_green and NR_red_edge are among the most sensitive vegetation indices to identify water stress in plants. These indices were generally able to detect changes observed in the hyperspectral curves. The index identified in this study as My_Index has been created using the wavelength at which the highest (700 nm) and lowest (410 nm) difference in reflectance for the treatments was found. Given the novelty of the index its interpretation is difficult at this point, however, since it is able to identify differences across the treatments (Figure 5), we believe it is a worthwhile candidate for future research.

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