Chromatic and Numerical Approaches for the Monitoring of Corn Plants under Moderate Water Stress

Gladimir V. G. Baranoski

Natural Phenomena Simulation Group

University of Waterloo, Canada

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Outline

- Introduction
- Investigation Framework
- Results and Discussion
- Concluding Remarks

Introduction

➢ Context

- The increasing reduction of freshwater supplies reported in many regions across the planet has a detrimental impact in corn (maize) crop yields

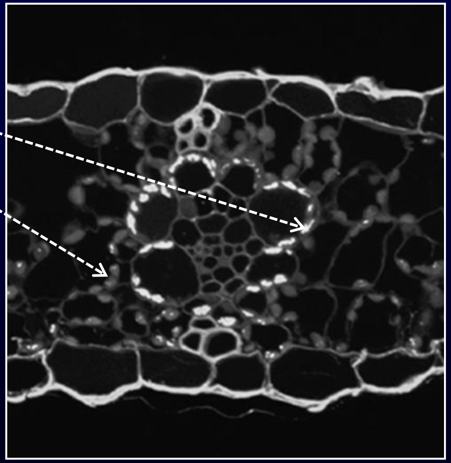
- Accordingly, the effects of water stress on these C4 plants has been extensively examined in several fields, from precison agriculture to remote sensing



➢ Biophysical background

- It is essential to detect and manage moderate (< 30 %) water reductions before irreversible damage to the corn leaves' photosynthetic apparatus can occur

- Corn (unifacial) leaves have their chloroplasts usually arrayed along the mesophyll cell walls, allowing for sieve effects (less light absorption)



- Chloroplast relocations elicited by *in vivo* water stress can increase detour effects (more light absorption)
    - darker leaves (Thomas *et al.*, 1971)
    - reflectance reduction (Maracci *et al*., 1991)

- Status quo
  - Corn leaves' chromatic changes are often subtle and their assessment can be impaired by varying illumination conditions
  - Multispectral indices can be employed to assist the monitoring of these plants

- Objectives
  - Investigate the sensitivity of corn leaves' chromatic attributes to changes in their optical properties brought about by *in vivo* moderate water stress
  - Propose a new moderate water stress index (MWSI)

Investigation Framework

Materials

- Virtual specimens (A1, A2, B1 and B2) representing real corn leaves used in the LOPEX (Leaf Optical Experiments) project (Hosgood *et al.*, 1995)

- For their wilted (moderate water stress) state, we adopted characterization changes based on observations reported in related works

- For instance, experiments by Woolley (1973) indicated that a 25% reduction in foliar water content was accompanied by:

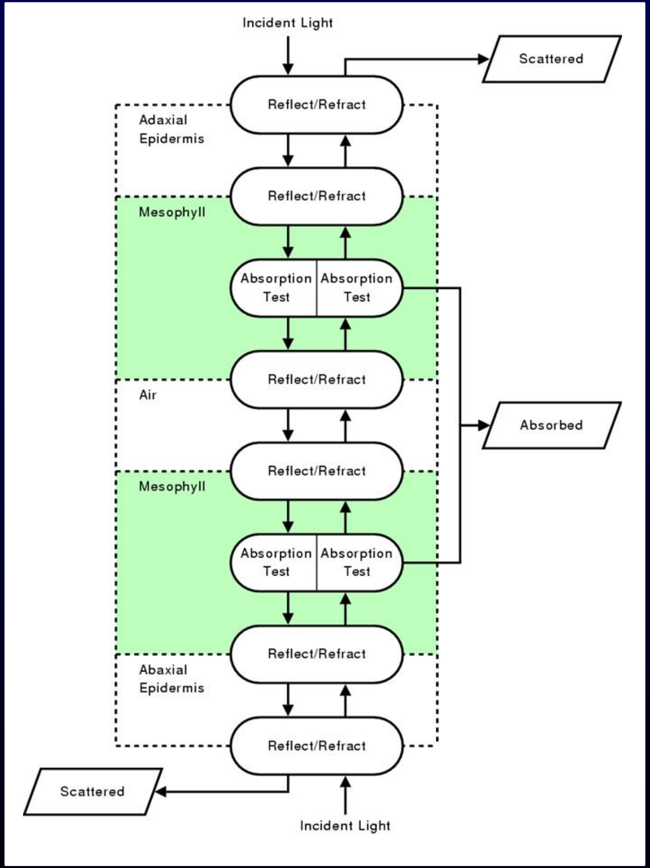
  - 20% decrease in leaf thickness

  - 2% decrease in leaf area

- *In silico* (computational) experiments

  - Spectral reflectance and transmittance curves were obtained using a first-principles model of light interactions with unifacial leaves: ABM-U
  - All curves were obtained considering an angle of incidence of 8 degrees and a 5 *nm* resolution
  - Chloroplast relocations during *in vivo* moderate water stress were accounted for

- For reproducibility purposes, we have made ABM-U available for online use



Remote Sensing of Environment, 2006

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ABM-U

Algorithmic BDF Model for Unifacial Plant Leaves

The ABM-U employs an algorithmic Monte Carlo formulation to simulate light interactions with unifacial plant leaves (e.g., corn and sugar cane). More specifically, radiation propagation is treated as a random walk process whose states correspond to the main tissue interfaces found in these leaves. For more details about this model, please refer to our related publications (2006 and 2007). Note that ABM-U provides bidirectional readings. However, one can obtain directional-hemispherical quantities (provided by our online system) by integrating the outgoing light (rays) with respect to the outgoing (collection) hemisphere. Similarly, bihemispherical quantities can be calculated by integrating the bidirectional scattering distribution function (BSDF, or simply BDF) values with respect to incident and collection hemispheres.

The default parameters (on the right) correspond to measured and estimated values for a corn (maize) leaf. The spectral input data files used by the online ABM-U model are available here.

For inquiries regarding this model's usage, please contact us via email.

* *The code for this version was last updated and compiled on October 2016.*

Run ABM-U Online

Enter your email address:
(used to send the results)

Model Parameter	Value
Number of samples	100000
Wavelength range	400-2500 nm
Angle of incidence	8 degrees
Surface of incidence	Adaxial
Leaf thickness	0.0204 cm
Mesophyll percentage	80 %
Chlorophyll A concentration	0.0029 g/cm^3
Chlorophyll B concentration	0.0008 g/cm^3
Carotenoids concentration	0.00066 g/cm^3
Protein concentration	0.05793 g/cm^3
Cellulose concentration	0.05804 g/cm^3
Lignin concentration	0.00661 g/cm^3
Cuticle undulations aspect ratio	10
Epidermis cell caps aspect ratio	5
Spongy cell caps aspect ratio	5
Simulate sieve effects	✓

Submit

http://www.npsg.uwaterloo.ca/models/ABMU.php

➢ Visual inspection of leaf swatches

- Leaf chromatic attributes obtained using standard colorimetry algorithms

leaf swatch

  - CIE illuminant: D65 (average daylight)
  - Simulated light interaction behaviours:
    - reflected light only (*e.g.*, leaf over an opaque surface)
    - reflected and transmitted light

- Computation of selected spectral indices using reflectance (ρ) values sampled at specific wavelengths

  - Proposed Moderate Water Stress Index:
    - MWSI = $(\rho(550) - \rho(400)) / (\rho(550) + \rho(400))$

  - Water Deficiency Reflectance Index 1:
    - WDRI1 = $(\rho(510) - \rho(560)) / (\rho(510) + \rho(560))$

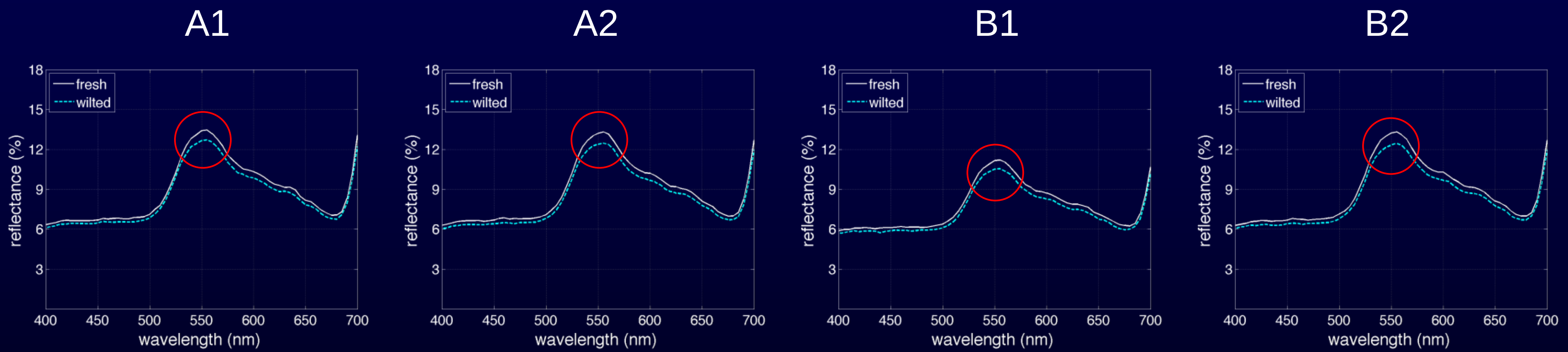
  - Photochemical Reflectance Index:
    - PRI = $(\rho(531) - \rho(570)) / (\rho(531) + \rho(570)) \times (-1)$

- Computation of MWSI*, WDRI1* and PRI* indices using aggregated reflectance and transmittance values sampled at the same wavelengths

Results and Discussion

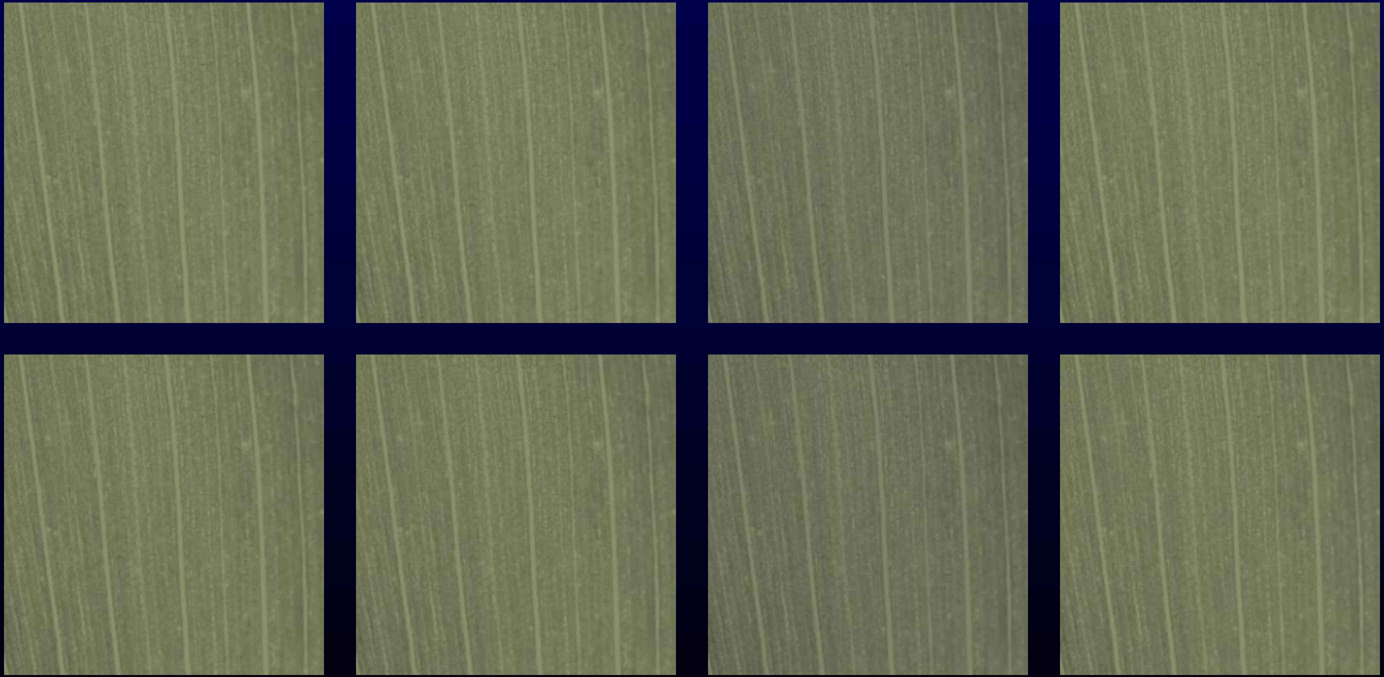
➢ Specimens' reflective behaviour

- Spectral curves



  - moderate water stress led to a reflectance decrease, notably around 550 *nm*
  - qualitative aggrement with measured spectral curves (Maraccci *et al.*, 1991)

- Swatches



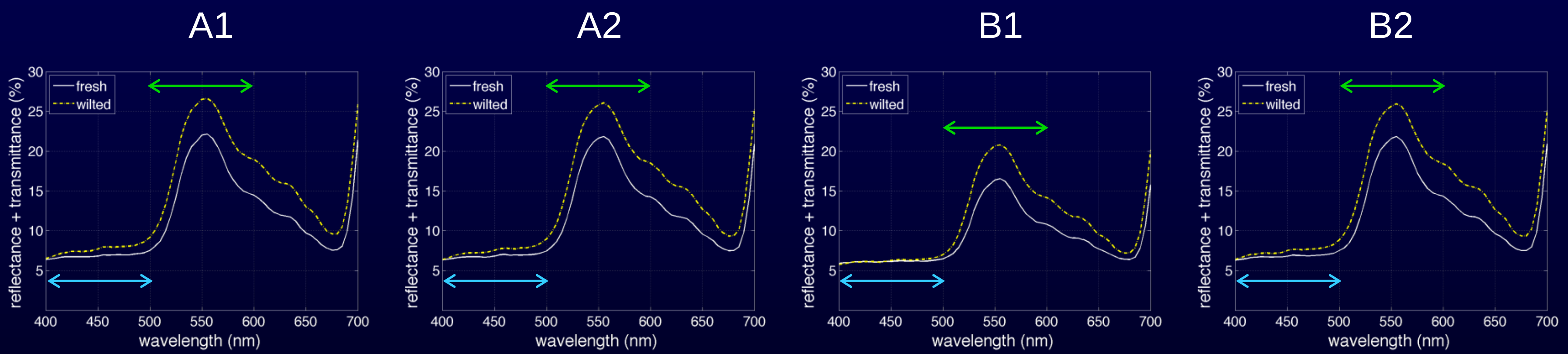
- Comparison of multispectral indices values and differences ($\delta_{f\text{-}w}$)

	WRDI1			PRI			MWSI		
Specimens	fresh	wilted	δ_{f-w}	fresh	wilted	δ_{f-w}	fresh	wilted	δ_{f-w}
A1	0.2570	0.2495	0.0075	0.0297	0.0226	0.0071	0.3578	0.3487	0.0091
A2	0.2555	0.2494	0.0061	0.0236	0.0208	0.0028	0.3537	0.3439	0.0098
B1	0.2317	0.2212	0.0105	0.0283	0.0249	0.0034	0.3102	0.2982	0.0120
B2	0.2593	0.2540	0.0053	0.0259	0.0235	0.0024	0.3559	0.3411	0.0148

- moderate water stress led to a reduction in the magnitude of the indices
- average differences for WRDI1 and PRI: 0.0074 and 0.0039, respectively
- MWSI average differences: 0.0114 > 0.01 (spectrophotometers' uncertainty)

➢ Specimens' aggregated reflective and transmissive behaviour

- Spectral curves



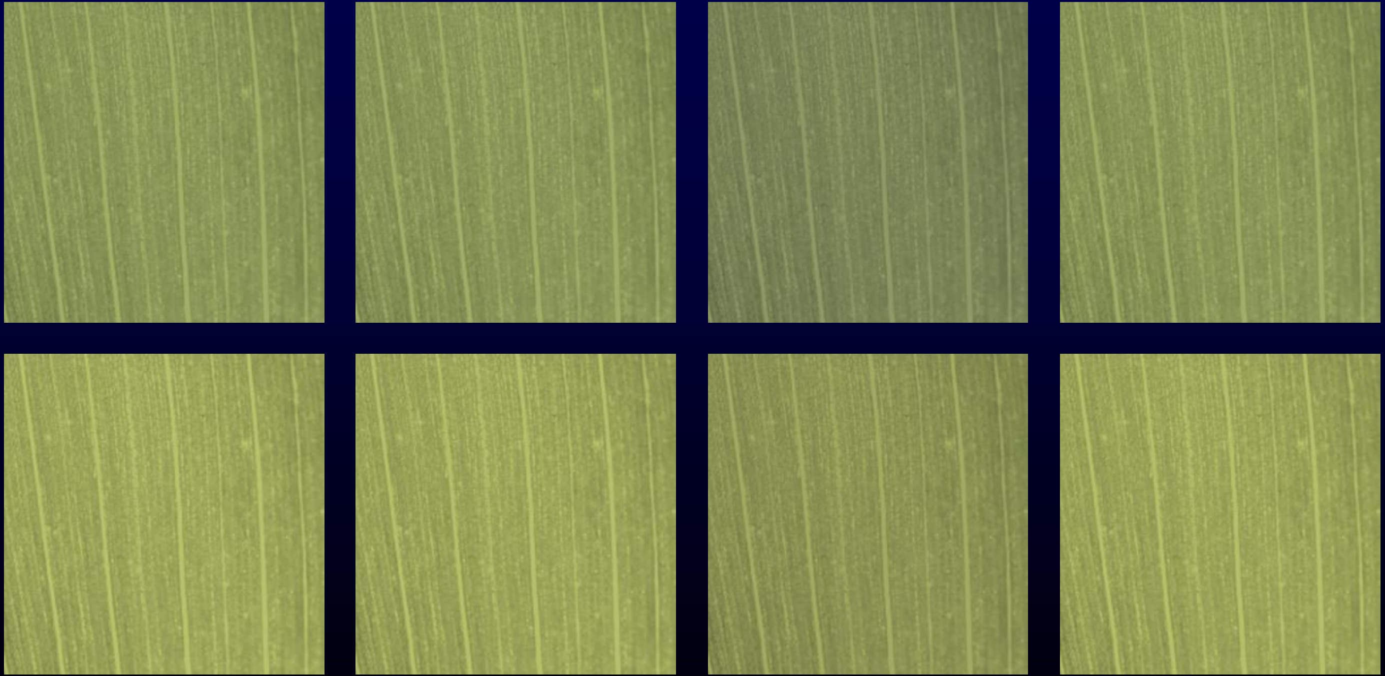
  - more light is propagated (reflected and transmitted) by the wilted specimens
  - these changes are more noticeable in the green (500 to 600 nm) region, and less noticeable in the blue (400 to 500 nm) region of the light spectrum

- Swatches

A1 A2 B1 B2

fresh

wilted



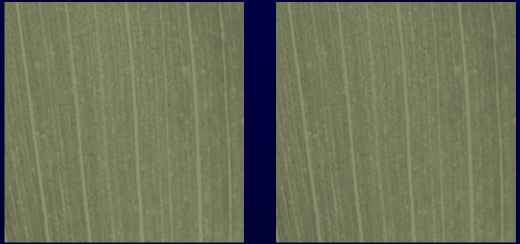
- Comparison of multispectral indices values and differences ($\delta_{f\text{-}w}$)

	WRDI1*			PRI*			MWSI*		
Specimens	fresh	wilted	δ_{f-w}	fresh	wilted	δ_{f-w}	fresh	wilted	δ_{f-w}
A1	0.4272	0.3976	0.0296	0.0476	0.0336	0.0140	0.5517	0.6069	-0.0552
A2	0.4257	0.4001	0.0256	0.0607	0.0482	0.0125	0.5478	0.6023	-0.0545
B1	0.3877	0.4248	-0.0371	0.0502	0.0456	0.0046	0.4714	0.5636	-0.0922
B2	0.4305	0.4074	0.0231	0.0507	0.0400	0.0147	0.5470	0.6005	-0.0535

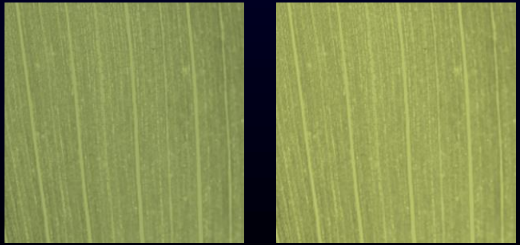
- PRI* differences increased and MWSI* differences decreased
- WRDI1* differences depicted inconsistent variations
- average differences for PRI* and MWSI* were 0.011 and 0.077, respectively

➢ Broader *in silico* observations

- Visual inspection of leaf chromatic attributes obtained considering only reflected light may not be a reliable indicator of *in vivo* moderate water stress

fresh  wilted

- The transmission of light through wilted leaves can have a significant impact on their chromatic attributes, and it warrants *in vivo* experiments

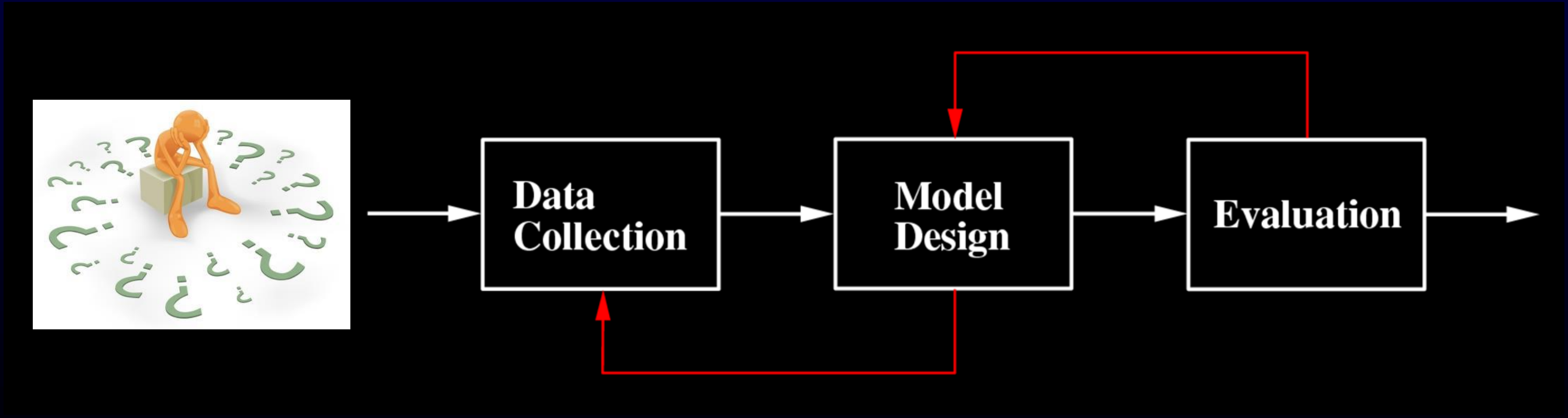
fresh  wilted

- Index differences computed using only reflectance values may be too small in certain cases to allow for a reliable monitoring of *in vivo* moderate water stress
  - WRDI1 and PRI differences < 0.01
- Index differences computed using reflectance and transmittance values may not always present a variation trend consistent with changes in foliar hydration levels
  - positive and negative WRDI1 differences

- Hurdles and opportunities ahead

  - A larger number of specimens and distinct experimental conditions need to be considered so that our preliminary observations can be generalized

  - The scarcity of measured reflectance and transmittance data for corn plants under *in vivo* moderate water stress hinders future advances in this area



- Once these aspects are addressed, new technologies in this area can be extended to other C_4 crops, like sugarcane, that are also:
  - extensively employed in food and biofuel production worldwide
  - object of environmental concerns (*e.g.*, excessive use of water and fertilizers)

Concluding Remarks

- The reliable monitoring of moderate water stress under *in vivo* conditions is essential for an ecologically sustainable increase in the yield of corn crops

- The current approaches based on the visual inspection of leaf appearance changes or the computation of multispectral indices have a limited efficacy

- *In silico* investigation frameworks can help to improve this scenario by enabling the controlled assessment of plants' responses to stress factors

- We remark that these frameworks are based on the use of computer models

- As stated by G. Box (1976), "all models are wrong", albeit some are useful

- Hence, a steeper rate of progress in this area will likely come about once the employed models' usefulness (predictive capabilities) can be fully verified
    - Notably with respect to the simulation of phenomena that are not completely understood such as the C_4 plants' mechanisms of adaptation to water stress
- To achieve that, it will be necessary to obtain more measured spectral data from *in vivo* experiments involving changes in the C_4 plants' hydration levels

Thank you!

Questions?