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Foliar Spectral Responses of Sugarcane and Maize: How Comparable are They?

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ABSTRACT

Sugarcane and maize (corn) crops are extensively used in the production of biofuel worldwide. These plants share important physiological and morphological traits. Both belong to the group of C4 species characterized by the presence of unifacial leaves. Moreover, their stress adaptation mechanisms make them less susceptible to adverse conditions elicited by climate changes. Given these aspects and their economical value, one would expect that there is no shortage of data for these plants, particularly with respect to their foliar spectral responses. After all, such data are essential for the efficacy of precision farming and remote sensing strategies devised to obtain an ecologically sustainable increase in the yield of these crops. However, this is not the case, with the data scarcity situation being markedly more serious for sugarcane. Because of that, and considering their physiological and morphological similarities, investigations on the spectral responses of C4 plants are usually conducted using data obtained from maize specimens, with the resulting findings often being implicitly extended to sugarcane. This raises the question of whether the level of comparability between the foliar spectral responses of these two species is sufficient to support such an approach. In this paper, we aim to contribute to the elucidation of this question. Using measured reflectance data obtained for maize and sugarcane leaves, we compute selected spectral features associated with these specimens, and assess possible discrepancy trends. We then discuss data availability issues in this area, and identify relevant topics for future research that will likely require comprehensive measured spectral datasets for these plants.

Keywords: sugarcane, maize (corn), reflectance, red edge position, red to far-red ratio, stress factors, agriculture, precision farming, remote sensing.

1. INTRODUCTION

Sugarcane (*Saccharum officinarum* L.) and maize (*Zea mays* L., corn) are two species extensively cultivated worldwide. In recent decades, the demand for these plants has increased substantially due to their use in the production of biofuel. To meet this high demand in an ecologically sustainable way, it has become essential to devise strategies to improve the yield of sugarcane and maize crops while avoiding the excessive use of freshwater and fertilizers, notably in regions more susceptible to adverse effects (*e.g.*, droughts and aridification) of climate change.[1–3]

A number of these strategies involve the use of precision farming and remote sensing technologies. The efficacy of these technologies, in turn, is tied to the availability of ground truth datasets about these plants' foliar spectral responses. Besides playing a central role in the evaluation of predictive computer models employed by these technologies, these datasets can also provide valuable insights about stress-triggered physiological mechanisms eliciting those responses.[4–10] Despite these aspects, the scarcity of foliar spectral is still an ongoing problem in this area.

Due its importance for food production, maize has been object of detailed experimental investigations involving the measurement of its spectral responses under different conditions. For instance, in the 1970's, Woolley[11,12] carried out a series of experiments that include the measurement of reflectance and transmittance of different maize specimens. Another noteworthy example took place in the 1990's, when spectral (reflectance and transmittance), morphological and biochemical measurements on 120 leaf specimens representative of more than 50

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different species, including maize, were conducted during the LOPEX (Leaf Optical Properties Experiment) project.[13]

The foliar spectral datasets obtained from those and other efforts provided an experimental basis for a wide range of multidisciplinary studies involving the spectral responses of maize leaves. However, these datasets are still insufficient for in-depth investigations of open scientific topics in this area, particularly those associated with stress factors affecting the plant development.

When it comes to sugarcane, the shortage of spectral data is even more serious. For instance, sugarcane was not among the species selected for the aforementioned measurement initiatives. Moreover, even though one can find reflectance data, albeit restricted to a few measurement geometries, for sugarcane leaves in the literature,[14,15] the same cannot be said about transmittance data. To make the situation more challenging, a significant fraction of spectral datasets available for sugarcane refers to canopies or cultivated fields composed of different sugarcane varieties or cultivars. Although these datasets can be used to support general investigations on the yield of sugarcane crops,[7,9] they are not suitable for more specific investigations (*e.g.*, on these plants' adaptation mechanisms to stress factors) requiring foliar spectral data.

Sugarcane and maize share several morphological and physiological traits. Both are C4 monocotyledonous species characterized by the presence of unifacial leaves. Given these common traits and the fact that there are more spectral data available for maize in the related literature, one question comes to mind: could the spectral data available for maize leaves be used to support investigations involving the foliar spectral responses of sugarcane leaves? In other words, are their foliar spectral responses similar enough, particularly when these plants are subjected to abiotic (*e.g.*, reduced nutrient and water supplies) or biotic (*e.g.*, weed competition) stress factors, to allow such an interspecies investigation approach?

In this paper, we attempt to address this question from an empirical perspective. To achieve that, we gathered measured reflectance data available for these plants in the literature. We then used these data to compute spectral features, namely the red edge position (REP)[16] and the red to far-red ratio (R/FR),[17] often employed in the assessment of these plant's capabilities to cope with stress factors.[5,7,18–21] The comparisons of the computed parameters are not meant to be exhaustive, especially considering the data scarcity problem highlighted earlier. In fact, our investigation aims to draw further attention to this problem, and serve as an additional catalyst for future initiatives aimed at the acquisition of comprehensive spectral datasets for these plants.

2. DATA AND METHODS

As we mentioned earlier, in this investigation, we employed measured reflectance datasets provided in the literature. For sugarcane, we used reflectance datasets obtained by Johnson *et al.*[15] for two representative varieties of sugarcane, namely noble cane (*Saccharum officinarum* L.) and wild cane (*Saccharum spontaneum* L.), as well as three sugarcane cultivars, namely L97-128, TUCCP77-042 and LPCP85-384. These datasets correspond to reflectance curves (from 350 to 850 nm, with a resolution of 5 nm), with each curve depicting the average of eight measurements conducted considering a normal (perpendicular) light incidence.

For maize, we used measured reflectance datasets made available to the scientific community by the LOPEX project.[13] These datasets consist in spectral files containing reflectance values (from 400 to 2500 nm, with a resolution of 1 nm), which were measured considering an angle of incidence of 8° (with respect to the specimens' normal vector). The employed LOPEX spectral files were acquired for four groups of maize leaf specimens, henceforth referred to as batches 1 to 4, with distinct morphological and biochemical characteristics.

Although one would prefer to use reflectance datasets obtained for both species considering the same light incidence geometry, to the best of our knowledge, this ideal combination is not readily available in the current literature. Alternatively, we attempt to locate and use reflectance datasets that were obtained using the most similar light incidence geometry. We note, however, that small deviations from a normal light incidence geometry (*e.g.*, less than 10°) tend to have a negligible impact on the reflectance of maize leaves.[22,23]

The REP corresponds to the peak value of the first derivative of a leaf specimen's reflectance curve in the spectral region between 680-800 nm.[16] Thus to obtain this parameter for a given reflectance curve, we first computed the curve's first derivative in the spectral region of interest using a three point numerical differentiation formula.[24] More precisely, we employed the following expression to compute the first derivative at a given wavelength (λ):

$$\rho'(\lambda) = (\rho(\lambda + 10) - \rho(\lambda - 10)) \times 0.05, \tag{1}$$

where $\rho(\lambda)$ denotes the reflectance (at the wavelength λ) sampled from the specimens' reflectance curve.

For consistency with the *in vitro* approach used to obtain the reflectance values considered in this investigation, we employed a formula based on the absorption peaks of chlorophyll (within the red and far-red bands of interest, namely 660 nm and 730 nm respectively, under *in vitro* conditions) to compute the R/FR ratios for the examined reflectance curves. This formula is expressed as:[25]

$$R/FR = \rho(660)/\rho(730). \tag{2}$$

We note that the findings reported in this paper remained the same when we employed a R/FR formula based on the absorption peaks of chlorophyll under *in vivo* conditions.[26] Thus, for conciseness, we elected to report only the results obtained using the formula indicated in Eq. 2.

3. RESULTS

In Table 1, we present the REP and R/FR values computed for the maize specimens. While the REP values varied from 720 to 729 nm, the R/FR values varied from 0.183 to 0.271. In Fig. 1, for comparison purposes, we present the red-region reflectance and corresponding derivative curves associated with three distinct REP values (720, 725 and 729 nm) computed for the maize specimens (LOPEX spectral files 1080, 0283 and 0535, respectively).

Batch 1			Batch 2			Batch 3			Batch 4		
File	REP	R/FR	File	REP	R/FR	File	REP	R/FR	File	REP	R/FR
0141	727	0.220	1076	727	0.251	0277	723	0.185	0535	729	0.207
0143	727	0.221	1078	726	0.271	0279	727	0.196	0537	729	0.211
0145	726	0.189	1080	720	0.268	0281	728	0.186	0539	727	0.202
0147	723	0.183	1083	727	0.215	0283	725	0.187	0541	729	0.203
0149	722	0.202	1084	722	0.267	0285	724	0.184	0543	726	0.184
Average	725	0.203	Average	724.4	0.255	Average	725.4	0.188	Average	728	0.201

Table 1: Red edge position (REP, in nm) and red to far-red ratio (R/FR) values computed for leaves belonging to five distinct batches of maize specimens collected during the LOPEX experiment.[13] The corresponding measured LOPEX spectral files used in the computations are also provided.

In Table 2, we present the REP and R/FR values obtained for the noble and wild cane varieties. One can observe that the parameter values obtained for noble sugarcane variety are completely outside the respective ranges of the values obtained for the maize specimens. For the wild sugarcane variety, although the REP value is within the range of the REP values obtained for the maize specimens, the R/FR value is outside the range of R/FR values obtained for the maize specimens. In Fig. 2, we present the red-region reflectance and corresponding derivative curves associated with the two examined sugarcane varieties.

Variety	REP	R/FR
Noble	712	0.421
Wild	725	0.397

Table 2: Red edge position (REP, in nm) and red to far-red ratio (R/FR) values computed for two representative varieties of sugarcane, namely noble (*Saccharum officinarum* L.) and wild cane (*Saccharum spontaneum* L.). The reflectance values used in the computations correspond to the average of eight measurements conducted by Johnson *et al.*[15] on each of the examined variety specimens.

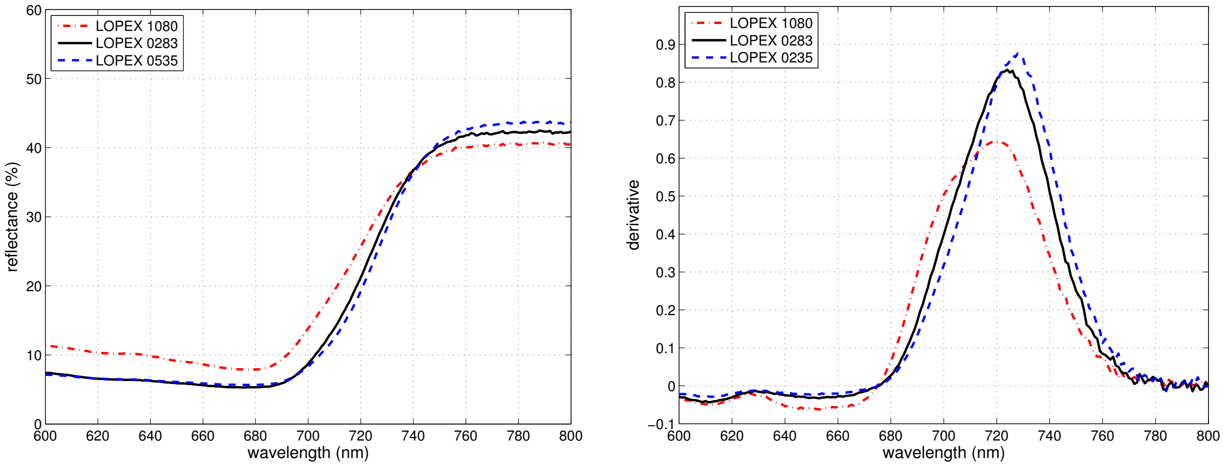


Figure 1: Red-region spectral data obtained for three representative maize leaf specimens. Left: measured reflectance curves (LOPEX spectral files 1080, 0283 and 0535) in the red region.[13] Right: corresponding computed derivative curves.

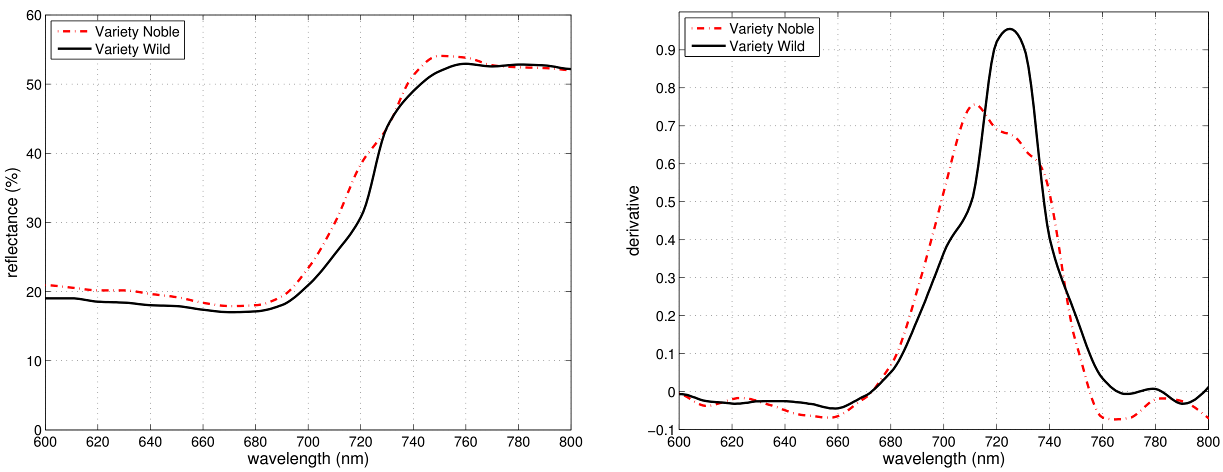
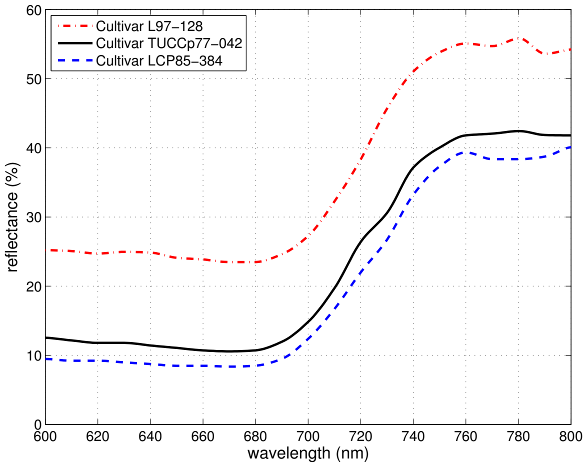


Figure 2: Red-region spectral data obtained for two representative varieties of sugarcane, namely noble cane and wild cane. Left: reflectance curves (each one depicts the average of eight measurements) provided by Johnson *et al.*[15] Right: corresponding computed derivative curves.

Lastly, in Table 3, we present the REP and R/FR values obtained for the sugarcane cultivars. With the exception of the REP value computed for the L97-128 cultivar, all other REP and R/FR values are outside the range of the values computed for the maize specimens. Again, for comparison purposes, in Fig. 2, we present the red-region reflectance and corresponding derivative curves associated with the examined sugarcane cultivars.

Cultivar	REP	R/FR
L97-128	724	0.522
TUCCP77-042	712	0.350
LPCP85-384	734	0.317

Table 3: Red edge position (REP, in nm) and red to far-red ratio (R/FR) values computed three representative sugarcane cultivars, namely L97-128, TUCCP77-042 and LPCP85-384. The reflectance values used in the computations correspond to the average of eight measurements conducted by Johnson *et al.*[15] on each of the examined cultivar specimens.



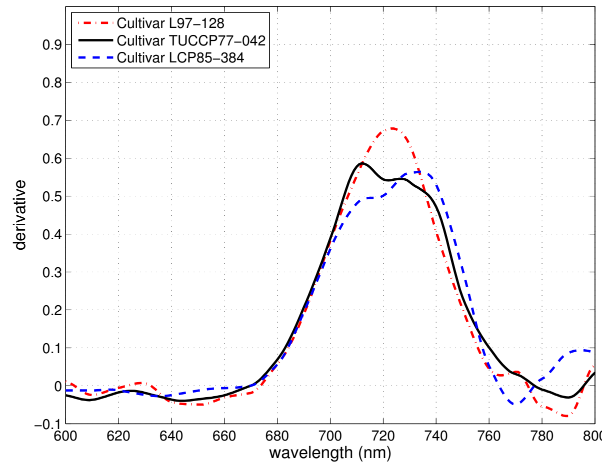


Figure 3: Red-region spectral data obtained for three representative sugarcane cultivars, namely L97-128, TUCCP77-042 and LPCP85-384. Left: reflectance curves (each one depicts the average of eight measurements) provided by Johnson *et al.*[15] Right: corresponding computed derivative curves.

4. DISCUSSION

Clearly, the relatively small number of examined specimens does not allow one to draw definitive conclusions. Nonetheless, some aspects could be verified. First, data scarcity is a serious issue in this area. We remark that the use of a small number of specimens in this investigation was mainly imposed by that. Second, despite the physiological and morphological similarities of sugarcane and maize, their reflective behaviours may present pivotal differences as illustrated by the computed spectral features.

Although one may claim that perhaps the use of a large number of maize specimens would expand the range of REP values, which, in turn, would encapsulated those values obtained for sugarcane, the R/FR ratios obtained for sugarcane are consistently larger than those obtained for maize. It has been observed[18,25] that even small variations in these ratios can alter the equilibrium of different phytochrome forms significantly, which can have a major impact on plant development.

As stated earlier, the amount of spectral data available for maize and sugarcane is still scarce, particularly to support in-depth investigations on the responses of these plants to stress conditions. To make matters worse, the available measured data is often obtained using distinct measurement specifications and under *in vitro* conditions. The latter aspect makes the establishment of cause-effect connections with live specimens more difficult. In the remainder of this section, we elaborate on this situation using water stress as a case study.

Most of the current knowledge about the foliar spectral responses of maize and sugarcane specimens to water stress conditions has been derived from *in vitro* experiments, *i.e.*, with spectral measurements conducted on leaf specimens detached from the plant. For illustrative purposes, in Fig. 4, we present graphs depicting foliar spectral reflectance (within the 500 to 1000 nm region) measured by Thomas *et al.*[27] and Maeda *et al.*[14] for *vitro* water-stressed maize and sugarcane specimens, respectively. In these graphs, one can observe the increase in reflectance elicited by the *in vitro* water stress.

By contrast, little is known about the spectral responses of maize and sugarcane leaves to *in vivo* water stress. To the best of our knowledge the only experimental dataset associated with these responses was obtained by Maracci *et al.*[28] for maize leaves. Their data, reproduced in the graphs presented in Fig. 5, indicated a reflectance decrease in the photosynthetic region, notably around 550 nm. Despite their statement that more experiments were required to confirm that behaviour, no additional measurements have been reported in the literature to date.

In 2012, Baranoski *et al.*,[23] using a first-principles model (ABM-U) for light interactions with unifacial plant leaves,[29] carried out simulations that qualitatively reproduced the reflectance decreased reported by

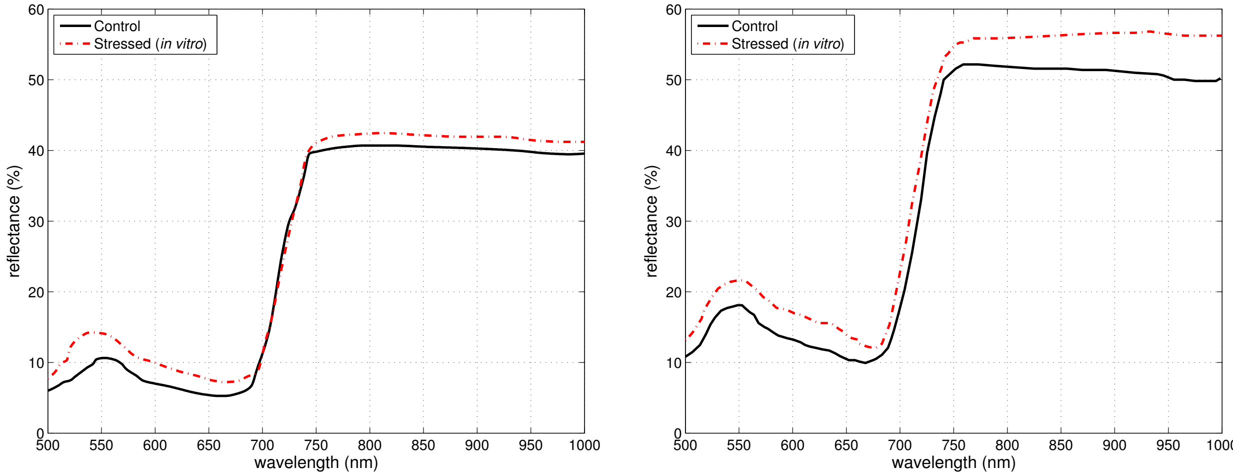


Figure 4: Reflectance data obtained for maize and sugarcane (*Saccharum* spp. cv. NiF8) leaves subjected to *in vitro* water stress (reduction of relative water content (RWC) of specimens detached from a plant). Left: curves measured by Thomas *et al.*[27] for control (RWC=83.9%) and stressed (RWC=74.0%) maize specimens. Right: curves measured by Maeda *et al.*[14] for control (RWC=94.5%) and stressed (RWC=25.0%) sugarcane specimens.

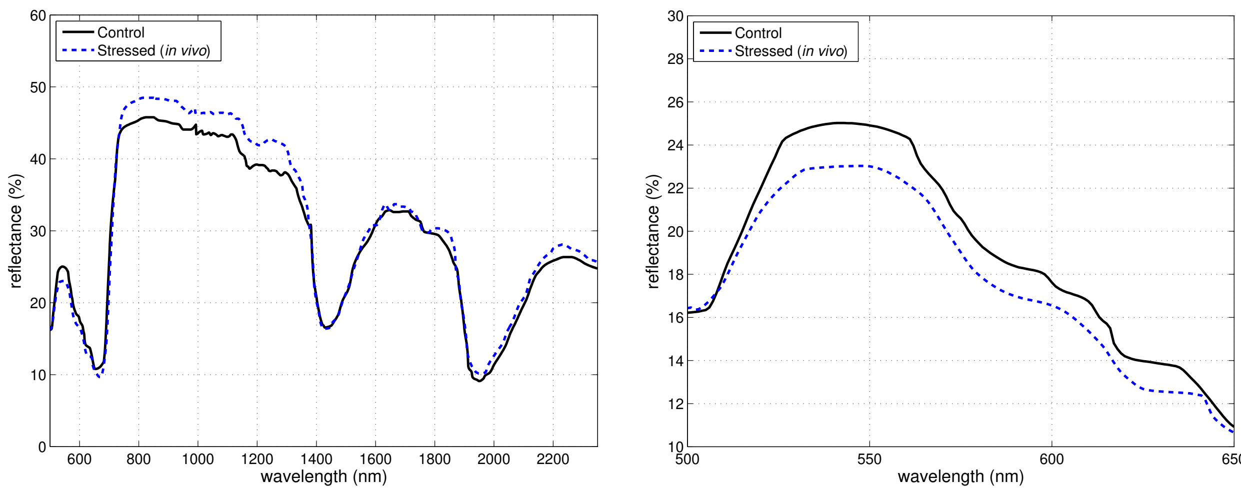


Figure 5: Reflectance curves measured by a Maracci *et al.*[28] considering a maize (*Zea mays* L., corn) specimen subjected to *in vivo* water stress (induced by withholding water from the soil). Left: 500 to 2350 *nm* range. Right: zoom-in, 500 to 650 *nm* range.

Maracci *et al.*[28] Those simulations considered the hypothesis that chloroplasts of maize leaves can reallocate and assume a more homogeneous distribution, which facilitates light absorption, in response to water deficit signals detected by the living plant. It is not clear whether this putative adaptive mechanism of maize leaves may also be found in sugarcane leaves. Again, to the best of our knowledge, similar experiments involving the spectral responses of sugarcane leaves to *in vivo* water stress have not been reported in the literature to date either.

The *in vivo* water stress scenario described above underscores the boundaries of the existing knowledge about key physiological processes affecting crops like maize and sugarcane. Undoubtedly, this situation is directly connected to the spectral data scarcity for these highly adaptable species, most notably for sugarcane. The same can be stated about studies connecting R/FR variations to weed competition. For these studies, not only the

R/FR ratios of reflected light are relevant, but also the R/FR ratios of transmitted light. As stated earlier, transmittance data for sugarcane leaves is not readily available in the current literature. Viewed in this context, we hope that our empirical investigation can increase the awareness for the need of more ground truth data about the foliar spectral responses, both in terms of reflectance and transmittance, for these species, particularly taking into consideration their strategic importance for ecologically sustainable food and biofuel production in an era increasingly affected by climate changes.

5. CONCLUDING REMARKS

Spectral data scarcity poses a significant challenge for the advance of the current knowledge about the spectral responses of C4 species and their capabilities to cope with stress factors. Besides increasing data availability, notably for sugarcane, efforts should also be focused on obtaining good quality spectral data, *i.e.*, data accompanied by detailed descriptions of the measurement conditions and specimen's characteristics. Without this supporting information, measured data has limited value for in-depth research investigations.

In the meantime, researchers have to use the available data to tackle the open questions involving these species. Given their biophysical similarities, one may consider using data obtained for unifacial maize leaves as references for high-level, qualitative studies involving unifacial sugarcane leaves. However, the preliminary outcomes of our investigation indicate that there may be subtle, albeit relevant, qualitative differences between the foliar spectral responses of these species.

These differences, in turn, may preclude the use of inferences from maize foliar spectral data to guide studies demanding a high degree of specificity of sugarcane foliar spectral responses. Such studies may include those research efforts aiming at increasing sugarcane crop yield while avoiding the excessive use of water and fertilizers. It also brings us again to the root of the problem, the shortage of spectral data in this area. On the positive side, this situation may offer new opportunities for comprehensive measurement initiatives that can have an impact on future scientific discoveries involving not only sugarcane and maize, but also a wide range of crop species.

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REFERENCES

[1] Earl, H. and Davis, R., "Effect of drought stress on leaf and whole canopy radiation use efficiency and yield of maize," *Agronomy Journal* **95**, 688–696 (2003).

[2] Linnenluecke, M., Nucifora, N., and Thompson, N., "Implications of climate change for the sugarcane industry," *WIREs Clim. Change* **9**, 498:1–34 (2018).

[3] Berdugo, M., Delgado-Baquerizo, M., Soliveres, S., Hernández-Clemente, R., Zhao, Y., Gaitán, J., Gross, N., Saiz, H., Maire, V., Lehmann, A., Rillig, M., Solé, R., and Maestre, F., "Global ecosystem thresholds driven by aridity," *Science* **367**, 787–790 (2020).

[4] Chen, K., P.Wang, Li, J., Zhang, J., and Zhong, L., "Canopy spectral reflectance feature and leaf water potential of sugarcane inversion," *Physics Procedia* **25**, 595–600 (2012).

[5] Fu, Y., Yang, G., Pu, R., Li, A., Li, H., Xu, X., Song, X., Yang, X., and Zhao, C., "An overview of crop nitrogen status assessment using hyperspectral remote sensing: Current status and perspectives," *European Journal of Agronomy* **124**, 126241:1–16 (2021).

[6] Katsoulas, N., Elvanidi, A., Ferentinos, K., Kacira, M., Bartzanas, T., and Kittas, C., "Crop reflectance monitoring as a tool for water stress detection in greenhouses: A review," *Biosystems Engineering* **151**, 374–398 (2016).

[7] Martins, J., Fiorio, P., Barros, P., Demattê, J., Molin, J., Cantarella, H., and Neale, C., "Potential use of hyperspectral data to monitor sugarcane nitrogen status," *Acta Scientiarum Agronomy* **43**(e47632), 1–13 (2021).

[8] Mefford, B., *Assessing Corn Water Stress using Spectral Reflectance*, Master's thesis, Department of Civil and Environmental Engineering, Colorado State University, USA. (2014).

[9] Miphokasap, P., Honda, K., Vaiphasa, C., Souris, M., and Nagai, M., "Estimating canopy nitrogen concentration in sugarcane using field imaging spectroscopy," *Remote Sens.* **4**, 1651–1670 (2012).

[10] Zhang, N., Li, P., Liu, H., Huang, T., Liu, H., Kong, Y., Dong, Z., Yuan, Y., Zhao, L., and Li, J., "Water and nitrogen in-situ imaging detection in live corn leaves using near-infrared camera and interference filter," *Plant Methods* **17**(117), 1–11 (2021).

[11] Woolley, J., "Reflectance and transmittance of light by leaves," *Plant Physiology* **47**, 656–662 (1971).

[12] Woolley, J., "Change of leaf dimensions and air volume with change in water content," *Plant Physiology* **41**, 815–816 (1973).

[13] Hosgood, B., Jacquemoud, S., Andreoli, G., Verdebout, J., Pedrini, G., and Schmuck, G., "Leaf optical properties experiment 93," Tech. Rep. Report EUR 16095 EN, Joint Research Center, European Comission, Institute for Remote Sensing Applications, Luxembourg (1995).

[14] Maeda, K., Ueno, M., and Kawamitsu, Y., "Non-destructive estimation of water status of sugarcane leaf using spectral reflectance measurement," *J. Agric. Meteorol.* **60**(5), 569–572 (2005).

[15] Johnson, R., Veremis, J., and Zimba, P., "Discrimination of sugarcane varieties with pigment profiles and high resolution, hyperspectral leaf reflectance data," *Journal Association Sugar Cane Technologists* **28**, 63–75 (2008).

[16] Baranoski, G. and Rokne, J., "A practical approach to estimating the red edge position of plant leaf reflectance," *International Journal of Remote Sensing* **26**(3), 491–505 (2005).

[17] Baranoski, G., "Assessing the effects of nutrient stress on the red to far-red ratios of light transmitted by unifacial plant leaves," in [*IEEE International Geoscience & Remote Sensing Symposium - IGARSS 2020*], 5187–5190 (2020).

[18] Ascencio, J. and Lazo, J., "The shade avoidance syndrome under the sugarcane crop," in [*Crop Plant*], Goyal, A., ed., 1–24, Intech, Rijeka, Croatia (2012). Chapter 8.

[19] Blanco, Y., Afifi, M., and Swanton, C., "The effect of light quality on maize: a tool for weed plants management," *Cultivos Tropicales* **36**(2), 62–71 (2015).

[20] Maddoni, G., Otegui, M., amd M. Chelle, B. A., and Casal, J., "Maize leaves turn away from neighboors," *Plant Physiol.* **130**, 1181–1189 (2002).

[21] Hatfield, J., Gitelson, A., Schepers, J., and Walthall, C., "Application of spectral remote sensing for agronomic decisions," *Agronomy J.* **100**, S–117–S–131 (2008).

[22] Walter-Shea, E., Norman, J., and Blad, B., "Leaf bidirectional reflectance and transmittance in corn and soybean," *Remote Sensing of Environment* **29**, 161–174 (1989).

[23] Baranoski, G., Kimmel, B., Chen, T., and Yim, D., "*In silico* assessment of environmental factors affecting the spectral signature of C4 plants in the visible domain," *International Journal of Remote Sensing* **33**(4), 1190–1213 (2012).

[24] Burden, R. and Faires, J., [*Numerical Analysis*], PWS Publishing Company, Boston, fifth ed. (1993).

[25] Smith, H., "Light quality, photoperception, and plant strategy," *Ann. Rev. Plant Physiol.* **33**, 481–518 (1982).

[26] Kasperbauer, M., "Far-red light reflection from green leaves and effects on phytochrome-mediated assimilate partitioning under field conditions," *Plant Physiol.* **85**, 350–354 (1987).

[27] Thomas, J., Namkem, L., Oerther, G., and Brown, R., "Estimating leaf water content by reflectance measurements," *Agronomy Journal* **63**, 845–847 (1971).

[28] Maracci, G., Schmuck, G., Hosgood, B., and Andreoli, G., "Interpretation of reflectance spectra by plant physiological parameters," in [*International Geoscience and Remote Sensing Symposium - IGARSS'91*], 2303–2306 (1991).

[29] Baranoski, G., "Modeling the interaction of infrared radiation (750 to 2500 nm) with bifacial and unifacial plant leaves," *Remote Sensing of Environment* **100**, 335–347 (2006).