Continuing Project

Characterizing abiotic and biotic tree stress using hyperspectral information

CAFS 20.80

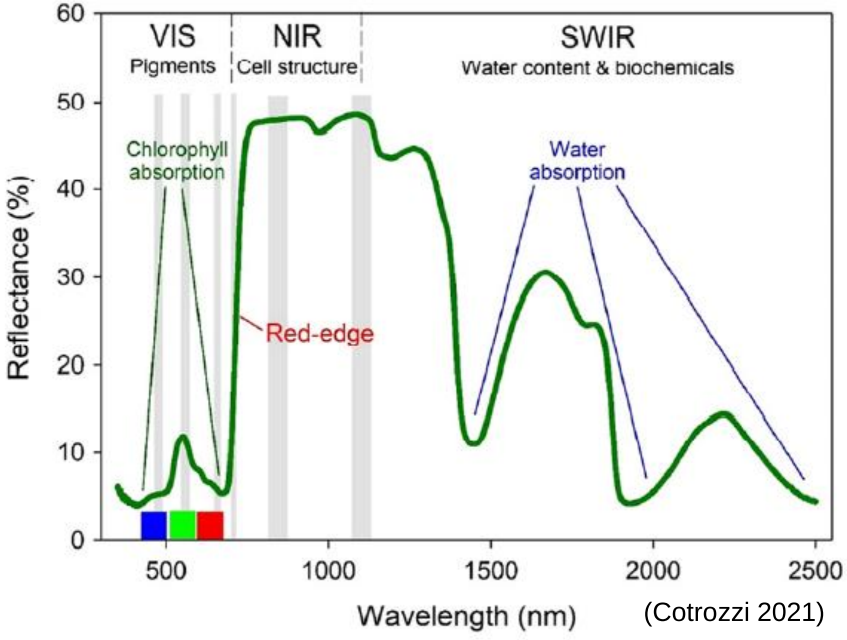
John Couture, Sylvia Park, Melba Crawford, Matthew Ginzel,
Brady Hardiman, Douglass Jacobs (Purdue University)
Aaron Weiskittel, Parinaz Rahimzadeh, Peter Nelson (University of Maine)
Cristian Montes, Caterina Villari, Kamal Ghandi (University of Georgia)

Sylvia Park (Purdue University)

Using remote sensing for monitoring forest health

Reflected light from plants could help assess foliar quality

Two directions:
-Capture finer details from foliage
-Survey the health of larger landscapes



(Cotrozzi 2021)

(Photo credit: Greg Asner)

We have three objectives:

1) determine the ability of hyperspectral data to provide information related to tree status in response to abiotic and biotic stress.

2) assess the reliability of hyperspectral information to scale from leaf, to tree, to stand, to landscape-level measurements.

3) evaluate the validity of hyperspectral data to characterize stress responses over different spatial and temporal scales in different geographic locations.

Reflectance spectroscopy
− *Tree stress response*

Black walnut at Martell Forest

- Tree species
  Black walnut (*Juglans nigra* L.)
- Environment
  Greenhouse, field
- Environmental stresses

	Study 1 (Greenhouse)	**Study 2** (Greenhouse)	**Study 3** (Field)
Abiotic	Drought, nutrient deficiency, salt deposition	Nutrient deficiency	Drought
Biotic	Fungal infection	Herbivory	






Reflectance spectroscopy
– *Tree stress response*

Trait data collection

Ex)
Li-6400
Pressure chamber
HPLC

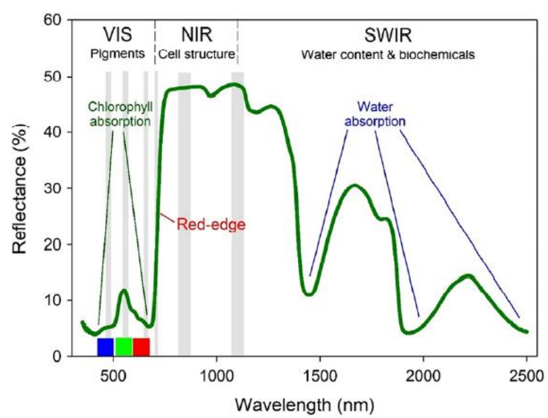


Leaf functional traits
- Gas-exchange
- Water
- Biochemical

Spectral data collection

Spectroradiometer
(SVC HR-1024i, 400-2400 nm)





(Cotrozzi 2021)

Study 1: Quantifying tree foliar chemical and physiological responses to abiotic and biotic stress using hyperspectral data

Specific objective:

Determine the ability of hyperspectral data 1) to estimate plant functional traits in responses to different stress events, alone and in combination and 2) to classify different abiotic and biotic stress events.

Four stress combinations

- Fungal infection + Soil quality
- Drought + Nutrient deficiency
- Fungal infection + Drought
- Nutrient deficiency + Salt deposition

Detection of tree stress responses

Leaf functional traits

1) Gas exchange related traits
2) Water related traits
3) Biochemical traits

using different analytical procedures and leaf spectral collections.

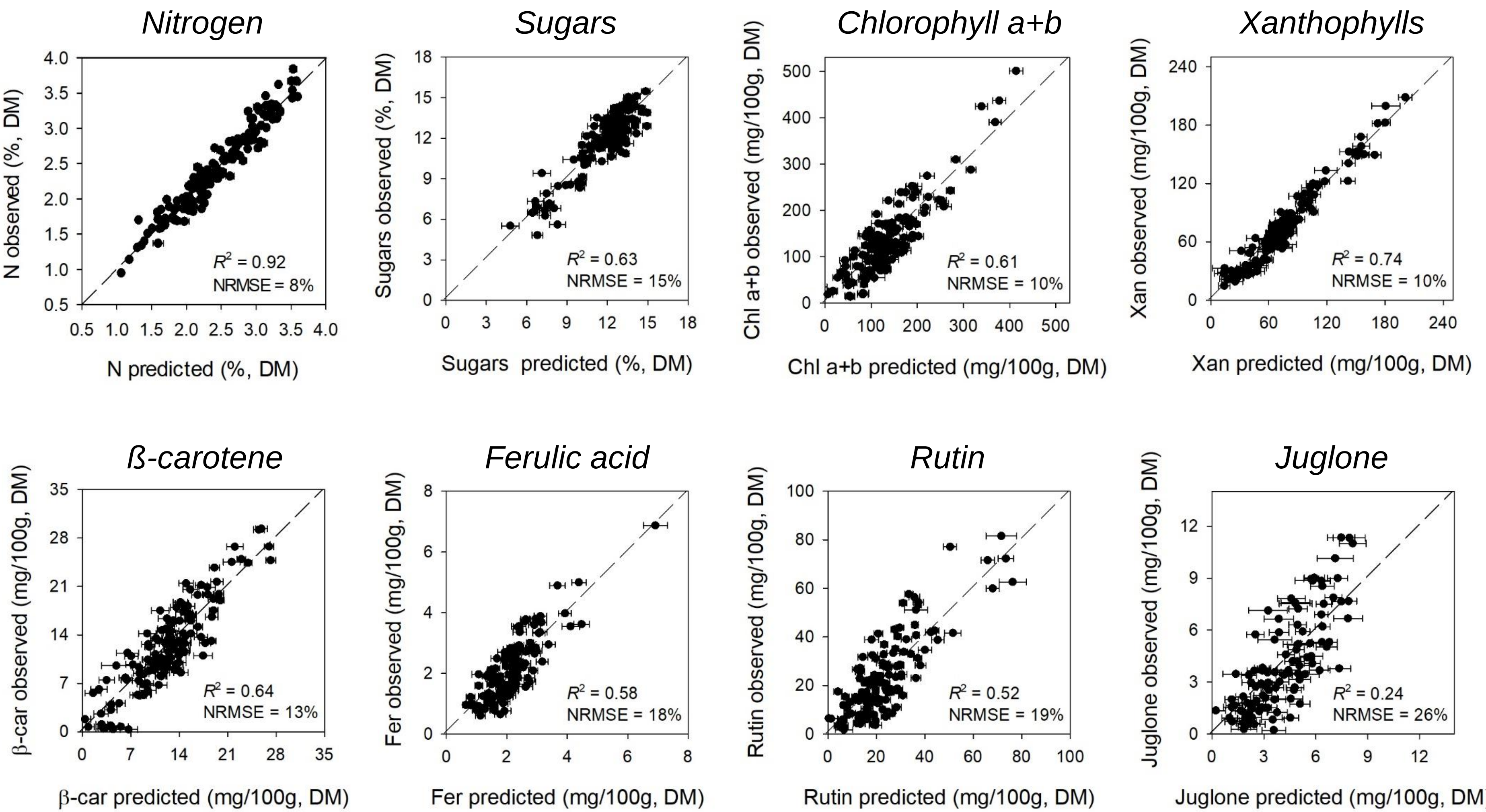
Biochemical traits

- 29 foliar biochemical traits were analyzed using high-performance liquid chromatography (HPLC) for trait retrievals.

Functional characterization	Traits	Details
Primary	Foliar nutrients	Carbon, nitrogen
	Pigments	Neoxanthin, violaxanthin, lutein, zeaxanthin, chlorophyll b, chlorophyll a, β-carotene
	Sugars	Sucrose, glucose, fructose
Secondary	Phenolic compounds	Phenolic acids, flavonoids, juglone

Biochemical traits − chemometric modelling

Trait retrievals



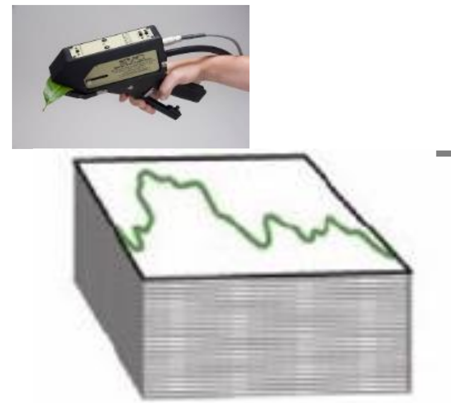
Leaf biochemical traits were well predicted by spectral data.

Trait retrievals + Spectral phenotyping

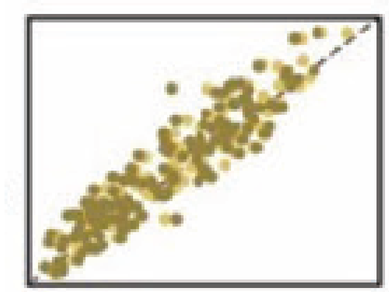
Four stress combinations

- Fungal infection + Soil quality
- Drought + Nutrient deficiency
- Fungal infection + Drought
- Nutrient deficiency + Salt deposition

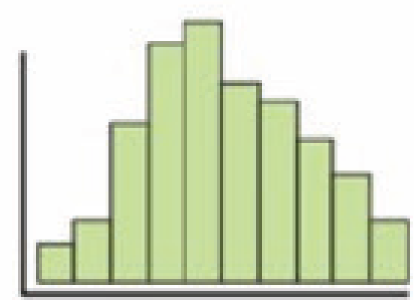
Spectral dataset



Apply model



Predicted traits



Q.
Can stress factors be identified by spectrally predicted traits?

Drought (*W*) + Nutrient deficiency (*N*) + Time length of stress (*T*)

		Gas-exchange related traits		Water-related traits			Biochemical traits					
Trait	***df***	***A***	***E***	Ψ_w	Ψ_π	**RWC**	**N**	**Sugars**	**Chl a+b**	**Xan**	**Rut**	**Ga**
W	1	***	***	***	**	***	*	n.s.	***	**	n.s.	n.s.
N	1	***	.	n.s.	.	n.s.	***	*	***	***	***	**
T	1	***	***	n.s.	***	**	n.s.	n.s.	***	***	***	***
W×*N*	1	n.s.	n.s.	.	*	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	.
W×*T*	1	**	n.s.	n.s.	*	**	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
N×*T*	1	n.s.	n.s.	n.s.	.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
W×*N*×*T*	1	n.s.	n.s.	n.s.	.	n.s.	.	n.s.	n.s.	n.s.	n.s.	n.s.

*** p < 0.001; ** < 0.01; * < 0.05; . < 0.1; n.s. not significant

A: Photosynthetic rate, *E* : Transpiration,
ψ_w: Water potential, ψ_π: Osmotic potential, RWC: Relative Water Content,
N: Nitrogen, Chl a+b: Total chlorophyll concentrations, Xan: Xanthophylls, Rut: Rutin, Ga: Gallic acid

Drought (*W*) + Nutrient deficiency (*N*) + Time length of stress (*T*)

		Gas-exchange related traits		Water potential								
Trait	***df***	***A***	***E***	Ψ_w	Ψ_π	**RWC**	**N**	**Sugars**	**Chl a+b**	**Xan**	**Rut**	**Ga**
W	1	***	***	***	**	***	*	n.s.	***	**	n.s.	n.s.
N	1	***	.	n.s.	.	n.s.	***	*	***	***	***	**
T	1	***	***	n.s.	***	**	n.s.	n.s.	***	***	***	***
W×N	1	n.s.	n.s.	.	*	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	.
W×T	1	**	n.s.	n.s.	*	**	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
N×T	1	n.s.	n.s.	n.s.	.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
W×N×T	1	n.s.	n.s.	n.s.	.	n.s.	.	n.s.	n.s.	n.s.	n.s.	n.s.

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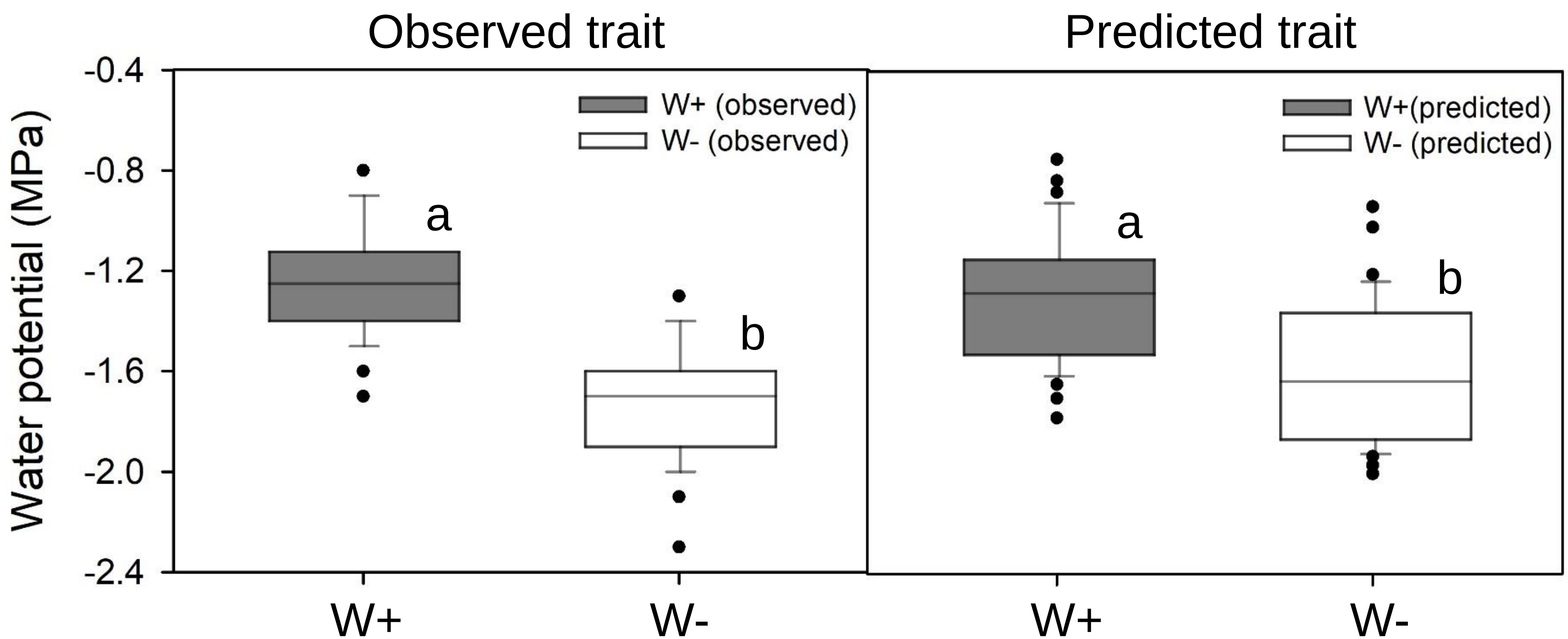
Predicted leaf water potential decreased in response to drought stress

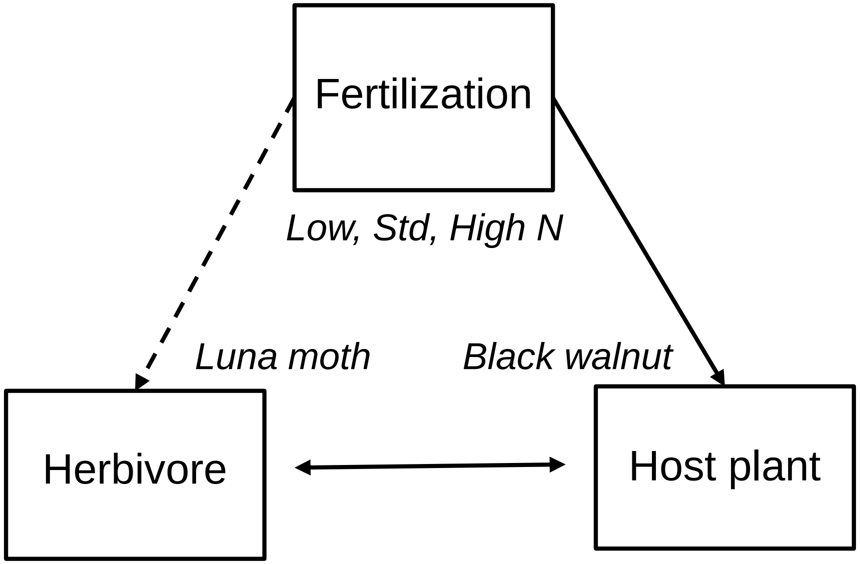


Hyperspectral data can be used for fast, non-destructive measurements for tree traits related to abiotic and biotic stress.

Study 2: Hyperspectral detection of induced plant defense responses to insect herbivory

Specific objective:

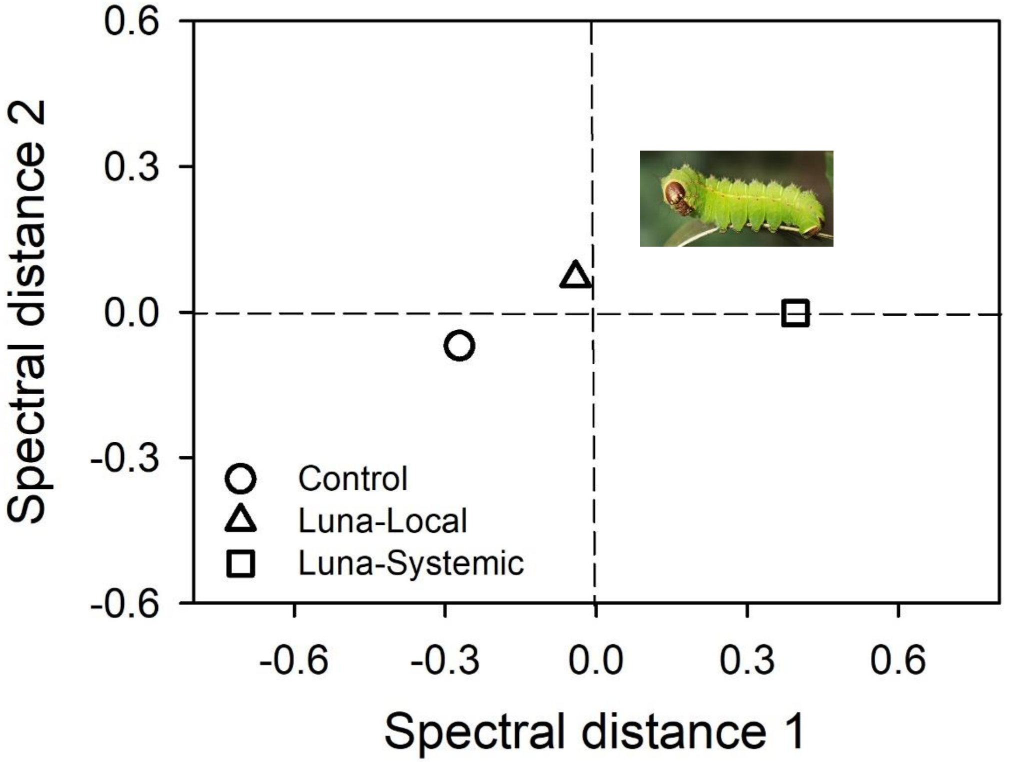
Determine how reliably hyperspectral data can detect local and systemic changes in chemical compounds in black walnut foliage in response to luna moth herbivory.



Spectral data identified the influence of luna moth herbivory on trees

*** $p < 0.001$; * < 0.05

Effect	*df*	F	*p*
Luna	2	10.91	***
N	2	3.40	*
Luna×N	4	2.10	*

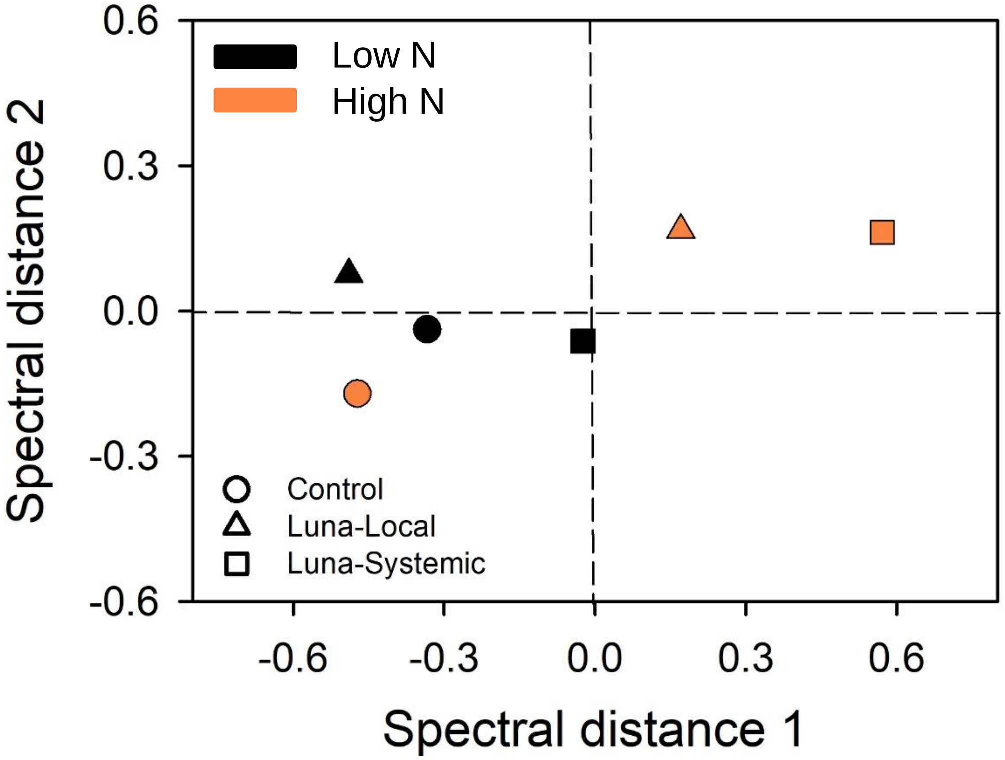


- Differences in spectral profiles among treatment groups were well detected in the full-range of spectral region (400–2400 nm).

Spectral data identified the influence of luna moth herbivory on trees

*** $p < 0.001$; * < 0.05

Effect	*df*	F	*p*
Luna	2	10.91	***
N	2	3.40	*
Luna×N	4	2.10	*



- Differences in spectral profiles among treatment groups were well detected in the full-range of spectral region (400–2400 nm).
- However, the change of spectral data to herbivory treatment depended on different N regimes.

Study 3: Growth and physiological responses of black walnut seedlings to drought under field condition

Specific objective:

Determine the ability of reflectance spectroscopy to accurately and rapidly assess field performance of seedlings, especially during the first year when they are most vulnerable.

Drought pre-conditioning:

- Control (85-95% moisture),
- Moderate (75-85% moisture),
- Extreme (55-65% moisture)

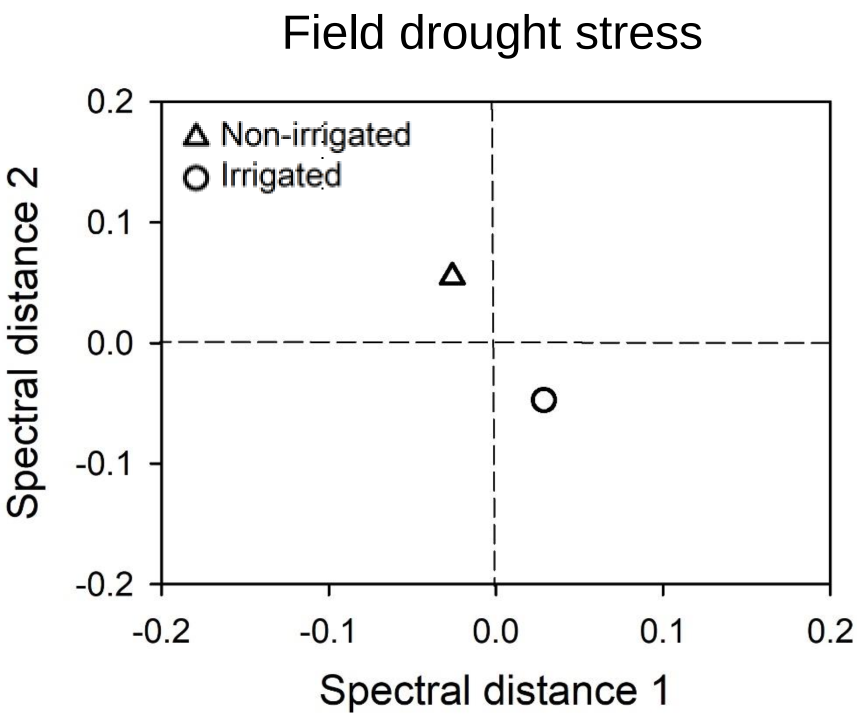
Seed sources:
Indiana, Maryland

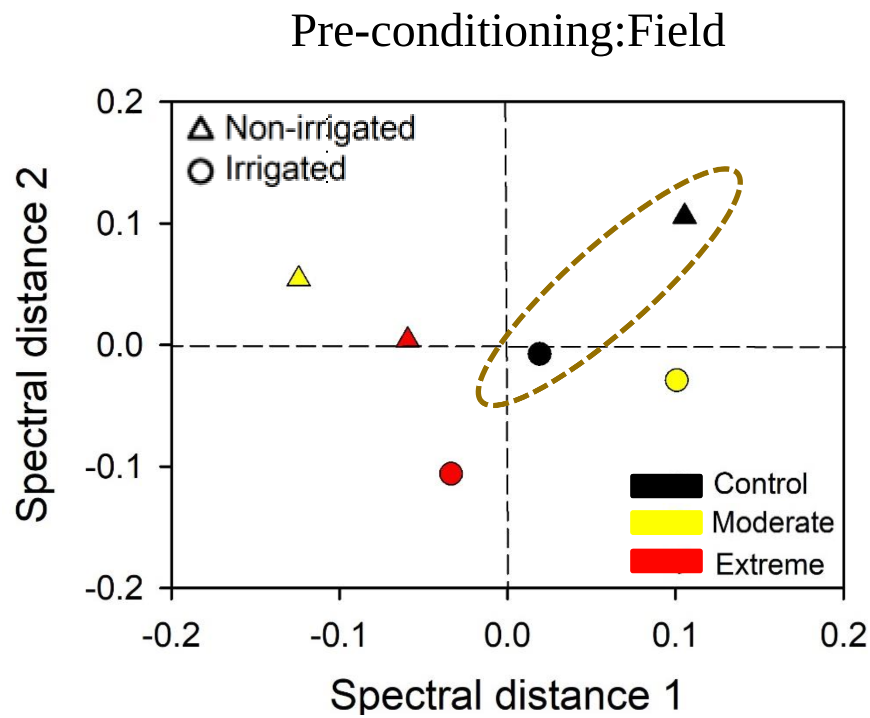
Field drought conditions:
Irrigated, non-irrigated

*** $p < 0.001$; * < 0.05; . < 0.1; n.s. not significant

Effect	*df*	F	*p*
Field drought stress	1	4.14	*
Drought pre-conditioning	2	2.37	.
Seed sources	1	9.71	***
Pre-conditioning:Field	2	2.38	.
Seed:Field	1	2.68	.
Pre-conditioning:Seed	2	1.36	n.s.
Pre-conditioning:Seed:Field	2	0.153	n.s.

- Differences in spectral data among treatment groups were well detected in infrared region (700–2000 nm).
- Spectral data classified different groups in drought treatment under field condition and in seed sources.





- Spectral data classified different groups in drought treatment under field condition.
- However, the change of spectral data to field drought treatment depended on drought preconditioning.

- Hyperspectral reflectance can 1) estimate foliar functional traits affected by different stressors and 2) classify different stress combinations.
- Spectroscopy simultaneously provides morphological, physiological, structural and biochemical information with a single spectral measurement, collected rapidly and non-destructively.
- Continued development of reflectance spectral technology will help train other forms of remote sensing and improve management efforts to mediate the negative impact of stressors in production forest systems.

Expected Deliverables − Long term

Long-term outcomes from this project will be the most advanced and extensive effort to date to integrate multi-modal RS products into precision forest management. Training of graduate students and postdoctoral scientists.

Dr. Ali Masjedi,
Bayer Crop Science

Dr. Behrokh Nazeri,
NASA ESSCA

Member Company Benefits

- Generate outcomes that can directly inform potential management decisions involving forest plantation management through more efficient and specific characterization of tree health using RS data.
- This project will be at a national-scale and should be relevant for all industry members.

Acknowledgements

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Plant-insect chemical ecology lab

Regeneration and Restoration Silviculture Laboratory

Mickelbart lab

Martell Wright center