Homeland Defense & Security
Information Analysis Center

Detecting Unexploded Ordnance Through Changes in Plant Health

Mr. Paul Manley

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HDIAC Subject Matter Expert – Missouri University of Science and Technology

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HDIAC Subject Matter Expert

April 25, 2018

Introduction

HDIAC and Today's Topic

HDIAC Overview

What is the Homeland Defense & Security Information Analysis Center (HDIAC)?

One of three Department of Defense Information Analysis Centers

Responsible for acquiring, analyzing, and disseminating relevant scientific and technical information, in each of its eight focus areas, in support of the DoD and U.S. government R&D activities

HDIAC's Mission

Our mission is to be the go-to R&D/S&T and RDT&E leader within the homeland defense and security (HDS) community, by providing timely and relevant information, superior technical solutions, and quality products to the DoD and HDS Communities of Interest/Communities of Practice.

HDIAC Overview

HDIAC Subject Matter Expert (SME) Network

HDIAC SMEs are experts in their field(s), and, typically, have been published in technical journals and publications.

SMEs are involved in a variety of HDIAC activities
- Authoring HDIAC Journal articles
- Answering HDIAC Technical Inquiries
- Engaging in active discussions in the HDIAC community
- Assisting with HDIAC Core Analysis Tasks
- Presenting webinars

If you are interested in applying to become a SME, please visit HDIAC.org or email info@hdiac.org.

Overview: Unexploded Ordnance (UXO) and Munitions Response

- **The detection of buried unexploded ordnance (UXO) is a key DoD capability for**
  - Battlespace support
  - Base/installation security
- **DoD and federal land-management agencies also oversee sites contaminated by fugitive explosive compounds**
- **Most UXO detection methods view vegetation as a hindrance to remote investigation—or at best, as neutral**
- **UXO detection methods that investigate vegetative response to explosive compounds can aid in**
  - Identifying areas of concern
  - Detecting long-term subsurface transport of explosive compounds
  - Distinguishing UXO sites from nonhazardous metallic items
- **This technology could aid DoD in its mission to identify, prioritize, and remediate contaminated defense sites**

Today's Presenters

Paul Manley
Missouri University of Science and Technology

Paul Manley is a doctoral student in civil engineering at Missouri University of Science and Technology (Missouri S&T). His work with explosives remote sensing began at Virginia Commonwealth University where he received his master's degree in biology. While at Missouri S&T, Manley has implemented remote sensing technologies into a lab primarily focused on plant-level uptake of contaminants. His goal is to develop explosives-specific metrics in order to safely and remotely located landmines and other UXO.

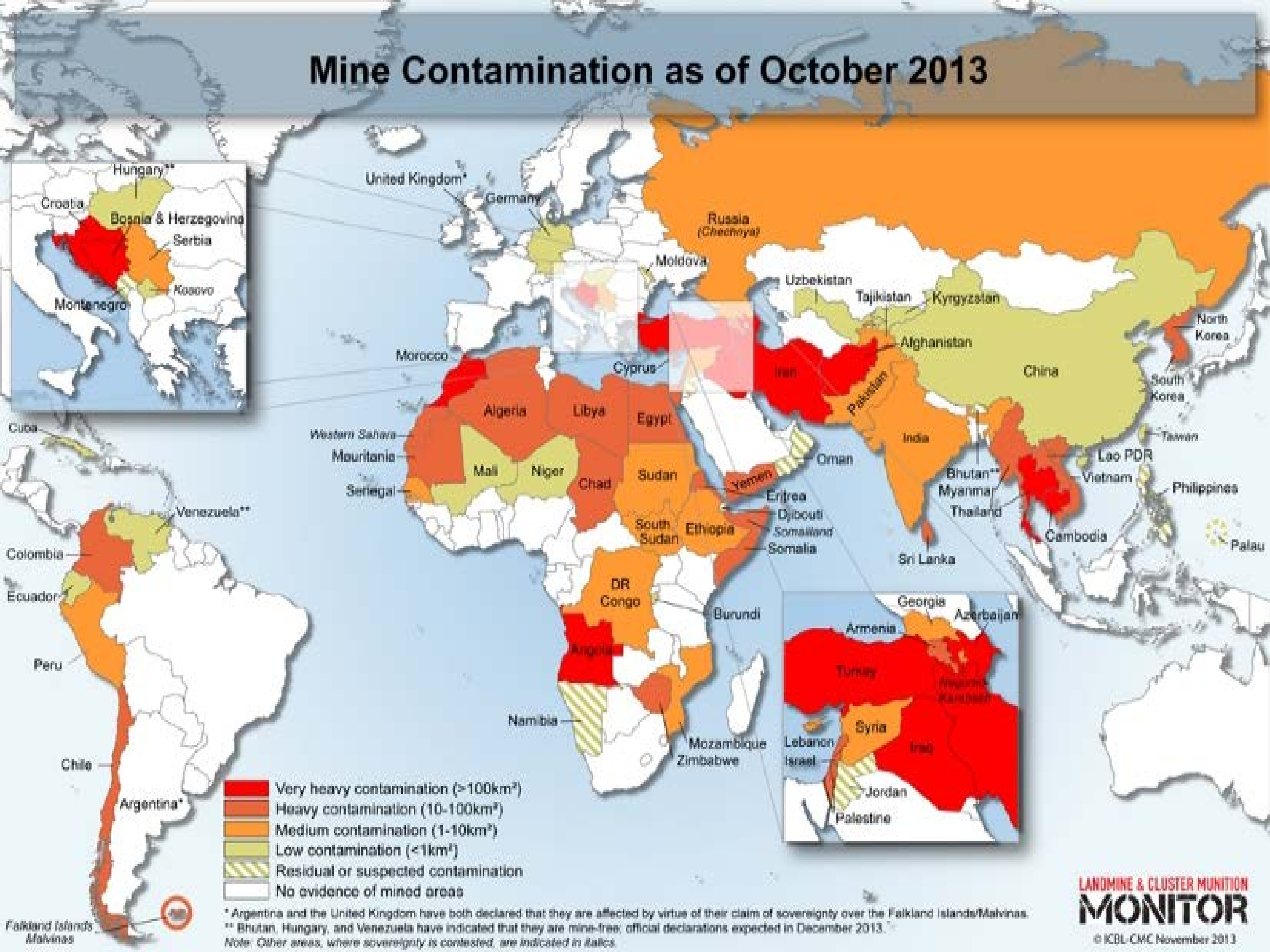
Joel Burken, Ph.D., P.E., BCEE, F.AEESP
Missouri University of Science and Technology

Dr. Joel Burken is the Curators' Distinguished Professor and Chair of the department of Civil, Architectural, and Environmental Engineering at Missouri S&T. He is also the Director of the Environmental Research Center for Emerging Contaminants at the university.

Introduction

Overview

- Plants are useful tools for assessing chemical signals in subsurface
- Agricultural species response to drought vs explosives is distinct
- Hyperspectral imaging efficacious in discerning between natural and anthropogenic stress
- Initial work demonstrates potential to advance technologies for:
  - Chemical delineation in the environment
  - Plant exposure to explosives
  - Remote sensing of subsurface UXO
- Research potentially impactful to DoD missions



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Serbia
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(Chechnya)
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Tajikistan
Kyrgyzstan
North Korea
Afghanistan
China
South Korea
Morocco
Cyprus
Iran
Pakistan
Algeria
Libya
Egypt
India
Taiwan
Cuba
Western Sahara
Mauritania
Mali
Niger
Oman
Lao PDR
Bhutan**
Vietnam
Senegal
Chad
Sudan
Yemen
Eritrea
Myanmar
Philippines
Thailand
Djibouti
Venezuela**
South Sudan
Ethiopia
Somaliland
Cambodia
Palau
Somalia
Sri Lanka
Colombia
Ecuador
DR Congo
Burundi
Georgia
Azerbaijan
Armenia
Peru
Angola
Turkey
Nagorno-Karabakh
Namibia
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Iraq
Lebanon
Mozambique
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Note: Other areas, where sovereignty is contested, are indicated in italics.
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Exposure Biology and the Exposome

www.niehs.nih.gov

Tree Coring

- Methods: D. Vroblesky - USGS
- Collect a core sample of the trunk/stem
- Core sample placed into vial
- Chemical analysis
- Partition coefficients determine concentrations

Phytoforensics - Plants as Samplers

Which chemicals can get in and which can't?

What does that mean?

Limmer, M.A., Burken, J.G. (2014). Plant translocation of organic compounds: Physicochemical predictors. *Environmental Science and Technology Letters*, 1(2), pp 156–161.

RGB

https://commons.wikimedia.org/wiki/
File:Iphone_4G-3_black_screen.png

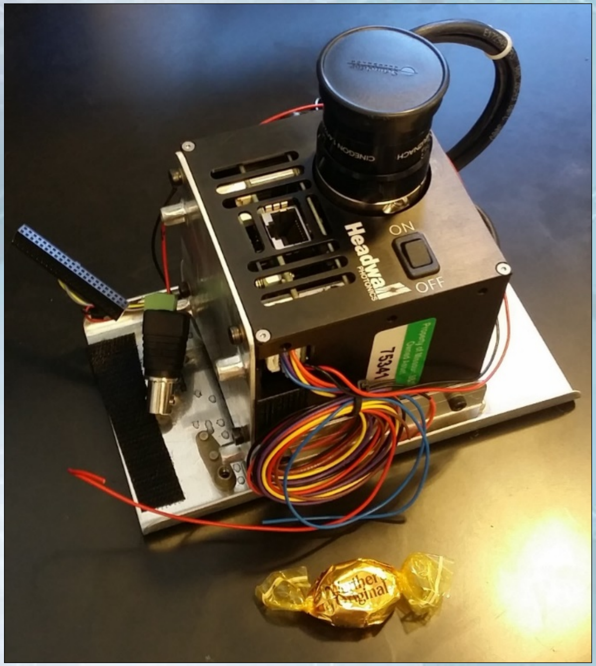
Adobe Stock

Adobe Stock

Multispectral

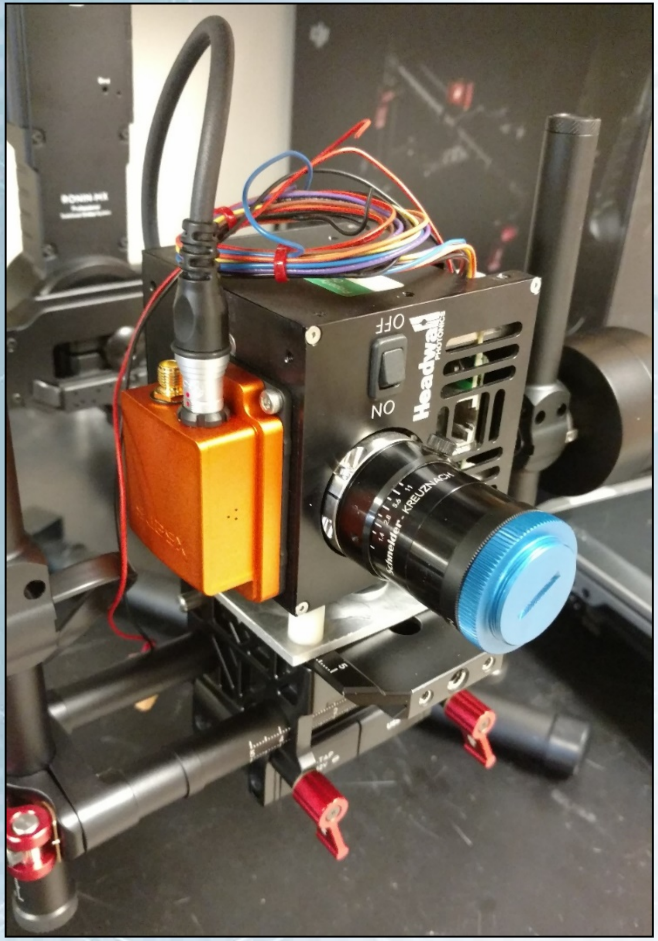
Adobe Stock

Hyperspectral



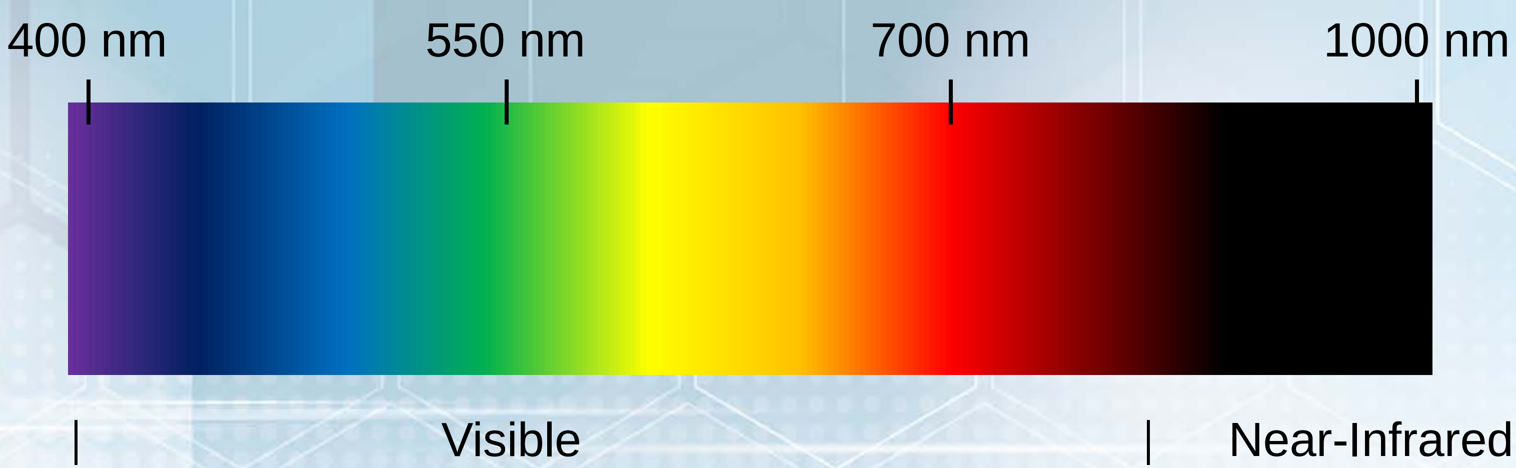
IMU

- Inertial Measurement Unit
- Camera is a line scanner

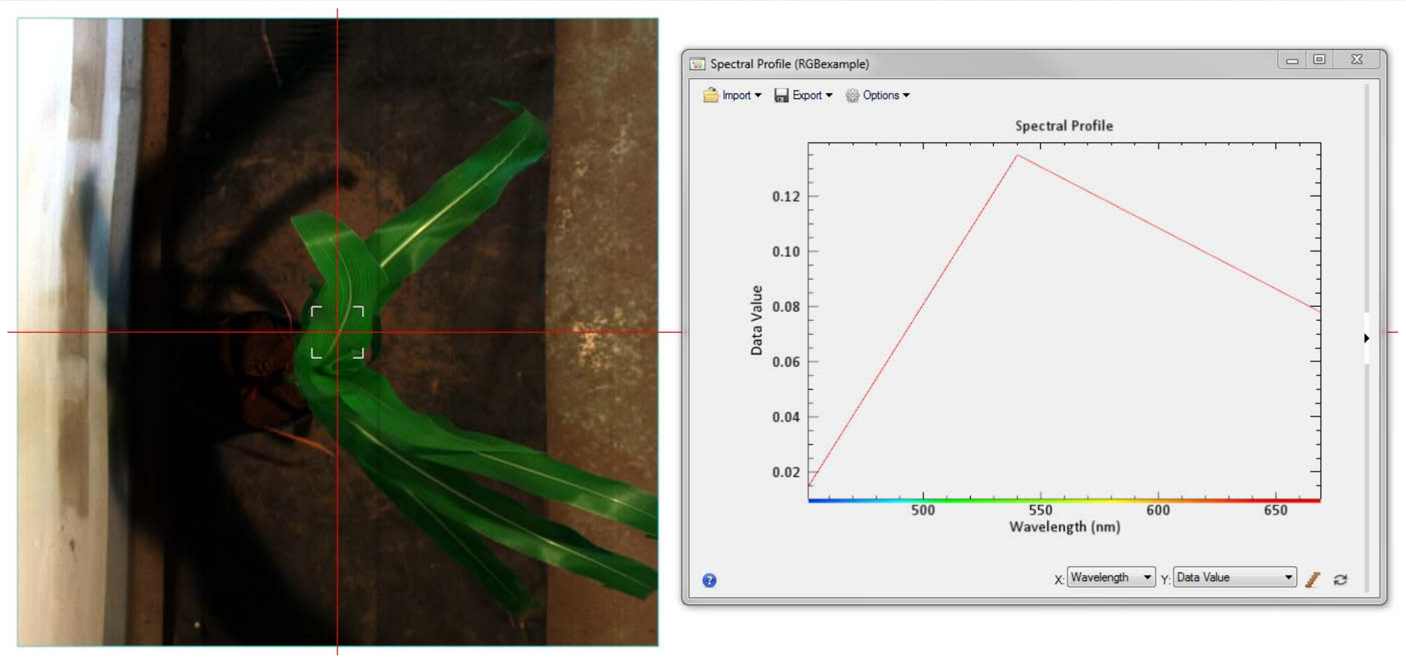


Electromagnetic Spectrum

RGB
Multispec
Hyperspec



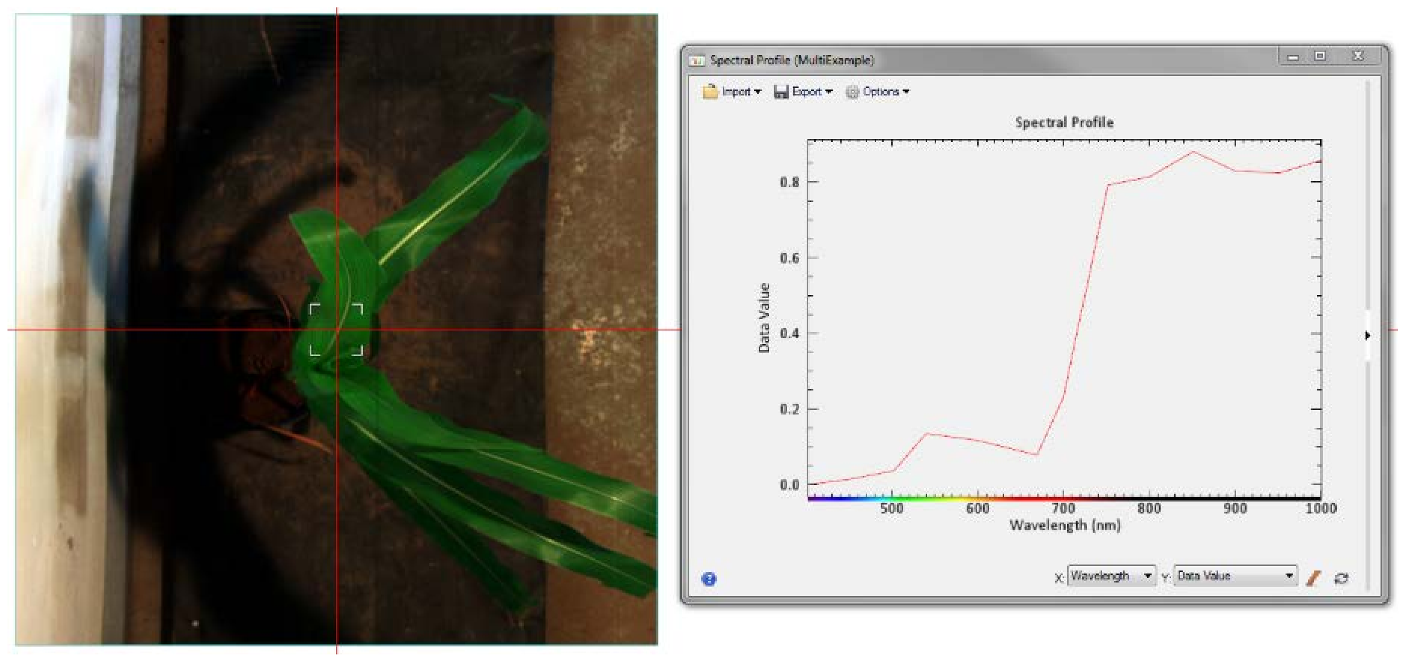
RGB



3 bands

Low spectral resolution

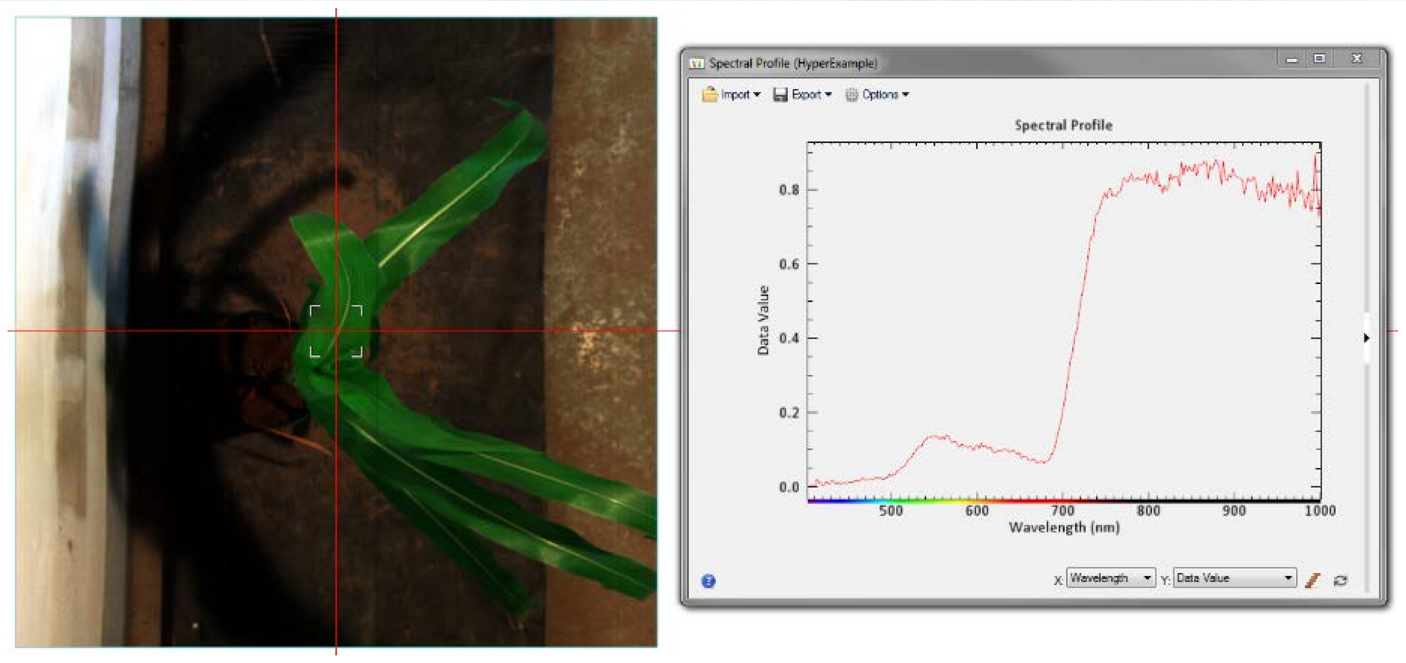
Multispectral



More than 3 bands

Good spectral resolution

Hyperspectral

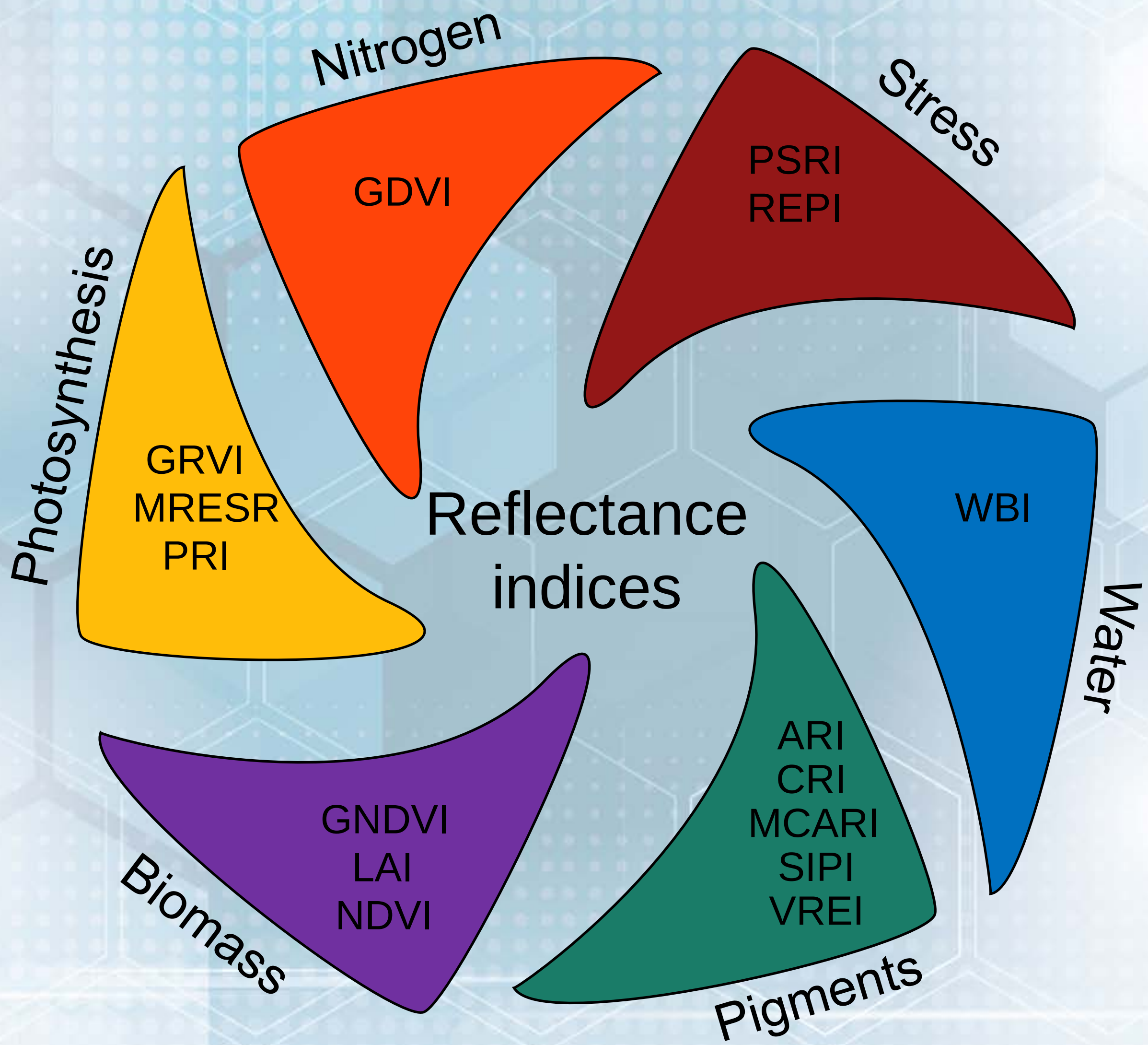


Hundreds of bands

High spectral resolution

Hyperspectral

- Higher spectral resolution
- Mineral identification
- Food safety
- Plant stress
- Nutrient
- Drought
- Chemical


Reflectance indices
Nitrogen
GDVI
Stress
PSRI
REPI
Water
WBI
Pigments
ARI
CRI
MCARI
SIPI
VREI
Biomass
GNDVI
LAI
NDVI
Photosynthesis
GRVI
MRESR
PRI

Reflectance Indices

Photochemical Reflectance Index (PRI)

- $$\frac{R_{531} - R_{570}}{R_{531} + R_{570}}$$
- $$\frac{\text{Carotenoids}}{\text{Chlorophyll}}$$

Normalized Difference Vegetation Index (NDVI)

- $$\frac{R_{800} - R_{670}}{R_{800} + R_{670}}$$
- Biomass

Simple algorithms related to plant physiology/morphology

HDIAC Homeland Defense & Security Information Analysis Center

Genesis

Plant and Soil

April 2010, Volume 329, Issue 1–2, pp 239–24

Remote detection of pl soil contamination

Authors Authors and affilia

Julie C. Naumann, John E. Anderson, Donald

Regular Article

First Online: 29 August 2009

Abstract

Our study was aimed at understandin contamination, and using optical met to visible changes. *Myrica cerifera* pl from 30–500 mg kg^{-1}. Physiological exposure at all treatment levels, and impairment rather than stomatal clos indices were able to detect TNT-indu concentrations occurred. The most se linked to fluorescence *in-filling* of the R_{735}/R_{850} may be attributed to both f in the near infrared region. This could have been influenced by transformation and conjugation

Int. J. Plant Sci. 173(9):1005–1014. 2012.

1058-5893/2012/17309-0005$15.00 DOI: 10.1086/667608

PLANTS AS PHYTOSENSORS: PHYSIOLOG IN RESPONSE TO RDX EXPOSURE AND

Julie C. Z

*United States Army Engineer Research and Development Cent and Department of Biology, Virginia Commonwea

Using plants as phytosensors could allow for large-s contamination. Quantifying physiological, photosyntheti 1,3,5-trinitro-1,3,5-triazine (RDX) contamination provid detection. Plants of the woody shrub *Baccharis halim* installations) were potted in soil concentrations of RD measurements of stomatal conductance and photosynth treatment levels, with no overall effect on water potent conductance were markedly different from those that occ and electron transport rate indicated that photosystem II photosynthetic reaction centers. Thus, declines in photos independent processes. Reflectance indices in the near- indices) were most affected and may reflect the pathwa compartmentalized in the vacuole, cell wall, or lignin. Th phytosensors to identify explosives exposure at remote

Keywords: chlorophyll fluorescence, electron transpor spectral reflectance, photosynthesis, RDX.

Introduction

Explosives have been released into the environment from munitions production and processing facilities and as buried unexploded ordnance. Millions of acres in the United States are contaminated with RDX (hexahydro-1,3,5-trinitro-l,3,5-triazine) and other explosives (Winfield et al. 2004). RDX is one of the primary compounds used by the US military, because of its high stability and detonation power (Jenkins et al. 1994). It is also a component found in land mines (along with trinitrotoluene, TNT), which are often encased in inexpensive, leaky containers, causing soil contamination (Rao et al. 2009). Subse-

and carried to the leaves through transpiration, transformed and conjugated with other compounds, and compartmentalized in the vacuole, cell wall, or lignin (Komoßa et al. 1995; Verkleij et al. 2009). Brentner et al. (2010) detected radiolabeled RDX in poplar leaves, indicating translocation of RDX

Plant Soil (2013) 366:133–141
DOI 10.1007/s11104-012-1414-1

REGULAR ARTICLE

Distinguishing natural from anthropogenic stress in plants: physiology, fluorescence and hyperspectral reflectance

Julie C. Zinnert · Stephen M. Via · Donald R Young

Received: 12 March 2012 / Accepted: 2 August 2012 / Published online: 23 August 2012

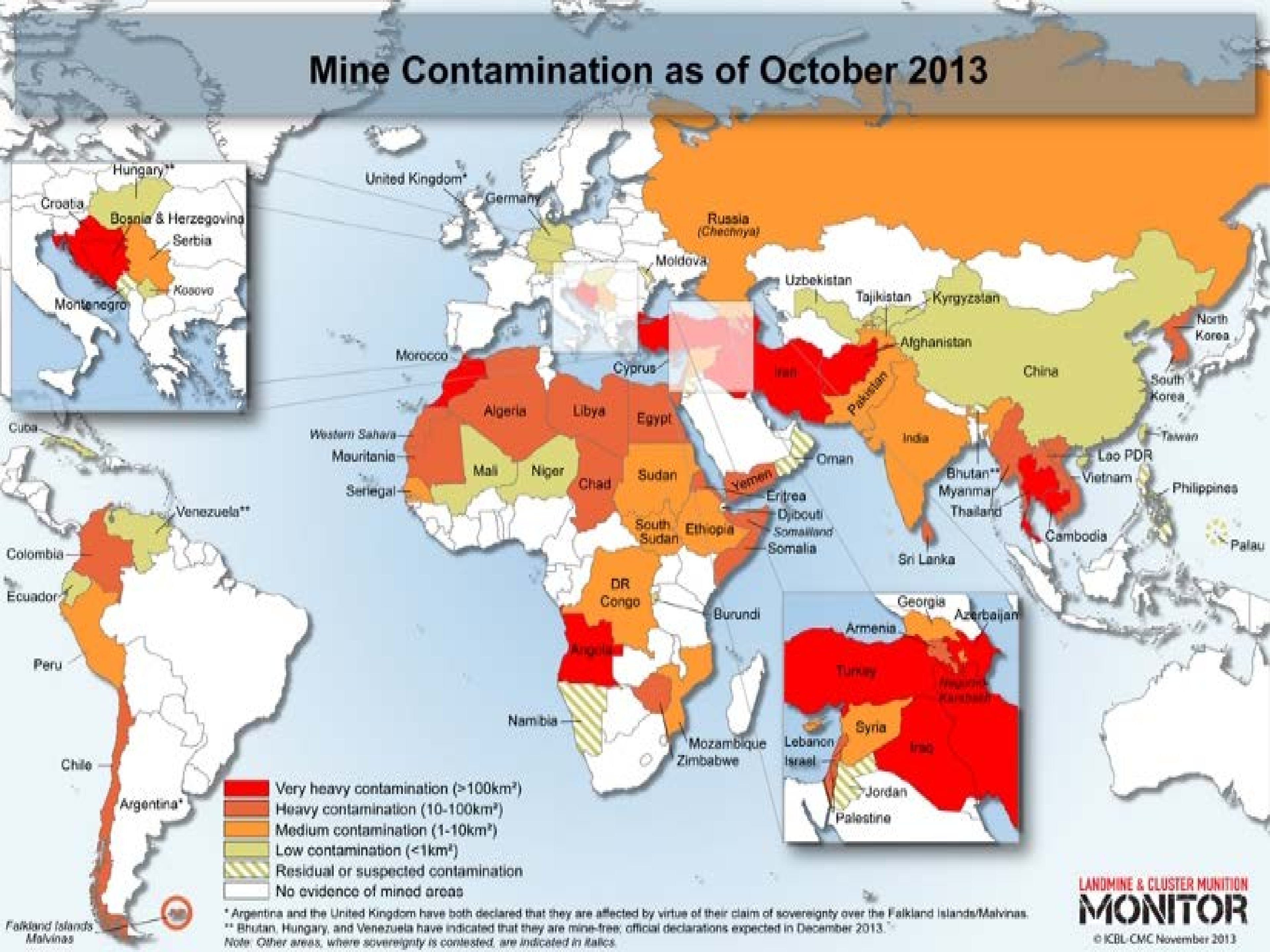
Abstract

Background and Aims Explosives released into the environment from munitions production, processing facilities, or buried unexploded ordnances can be absorbed by surrounding roots and induce toxic effects in leaves and stems. Research into the mechanisms with which explosives disrupt physiological processes could provide methods for discrimination of anthropogenic and natural stresses. Our objectives were to experimentally evaluate the effects of natural stress and explosives on plant physiology and to link differences among treatments to changes in hyperspectral reflectance for possible remote detection.

Methods Photosynthesis, water relations, chlorophyll fluorescence, and hyperspectral reflectance were measured following four experimental treatments (drought, salinity, trinitrotoluene and hexahydro-1,3,5-trinitro-l,3,5-triazine) on two woody species. hyperspectral results were used to evaluate the differences among treatments.

Results Explosives induced different physiological responses compared to natural stress responses. Stomatal regulation over photosynthesis occurred due to natural stress, influencing energy dissipation pathways of excess light. Photosynthetic declines in explosives were likely the result of metabolic dysfunction. Select hyperspectral indices could discriminate natural stressors from explosives using changes in the red and near-infrared spectral region.

Conclusions These results show the possibility of using variations in energy dissipation and hyperspectral reflectance to detect plants exposed to explosives in a laboratory setting and are promising for field application using plants as phytosensors to detect explosives contamination in soil.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India
Taiwan
Cuba
Western Sahara
Mauritania
Mali
Niger
Chad
Sudan
Oman
Yemen
Lao PDR
Bhutan**
Vietnam
Myanmar
Thailand
Philippines
Senegal
Eritrea
Djibouti
Somaliland
Venezuela**
South Sudan
Ethiopia
Somalia
Cambodia
Palau
Colombia
Sri Lanka
DR Congo
Ecuador
Burundi
Georgia
Armenia
Azerbaijan
Turkey
Nagorno-Karabakh
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Note: Other areas, where sovereignty is contested, are indicated in italics.
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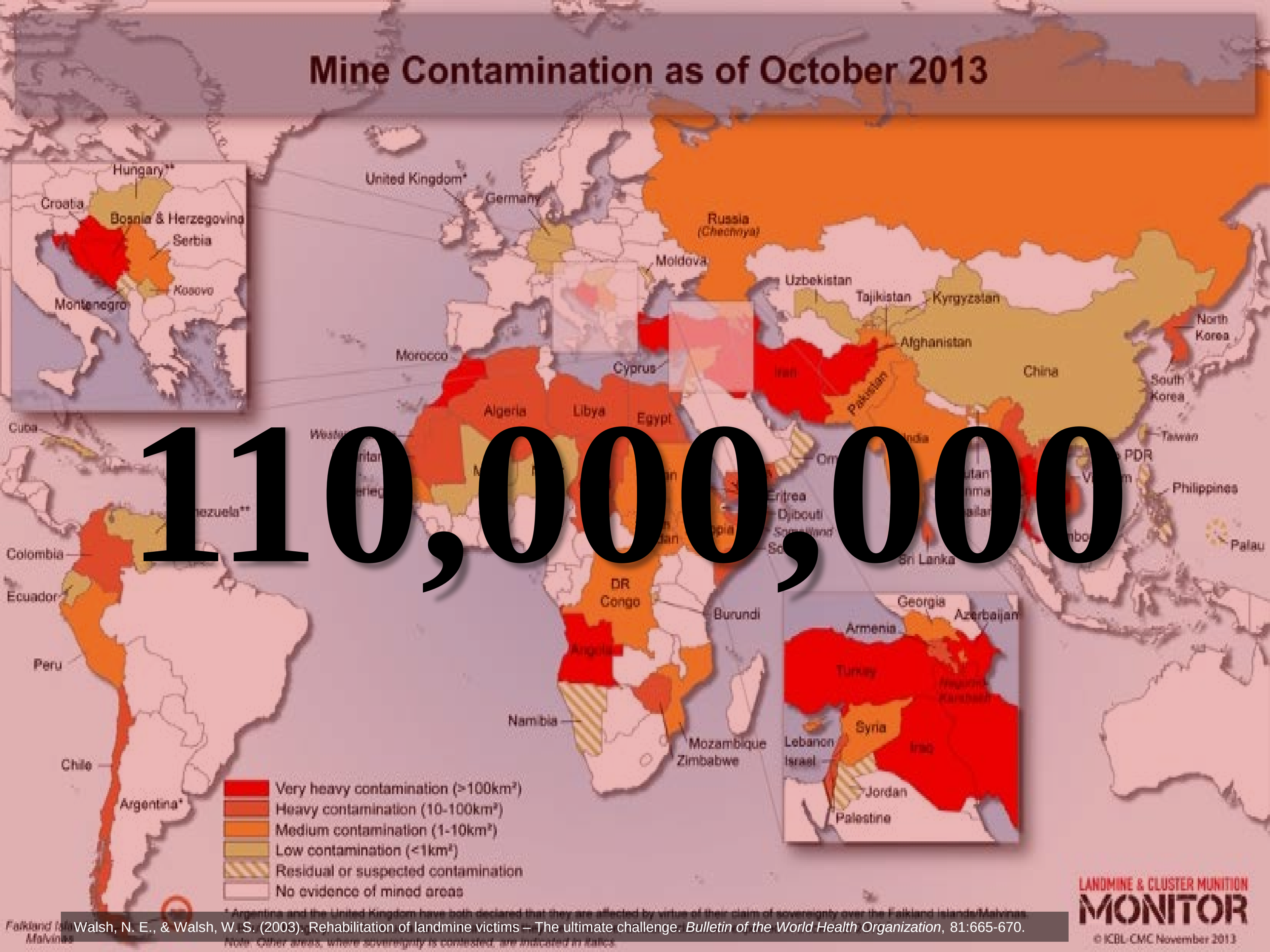

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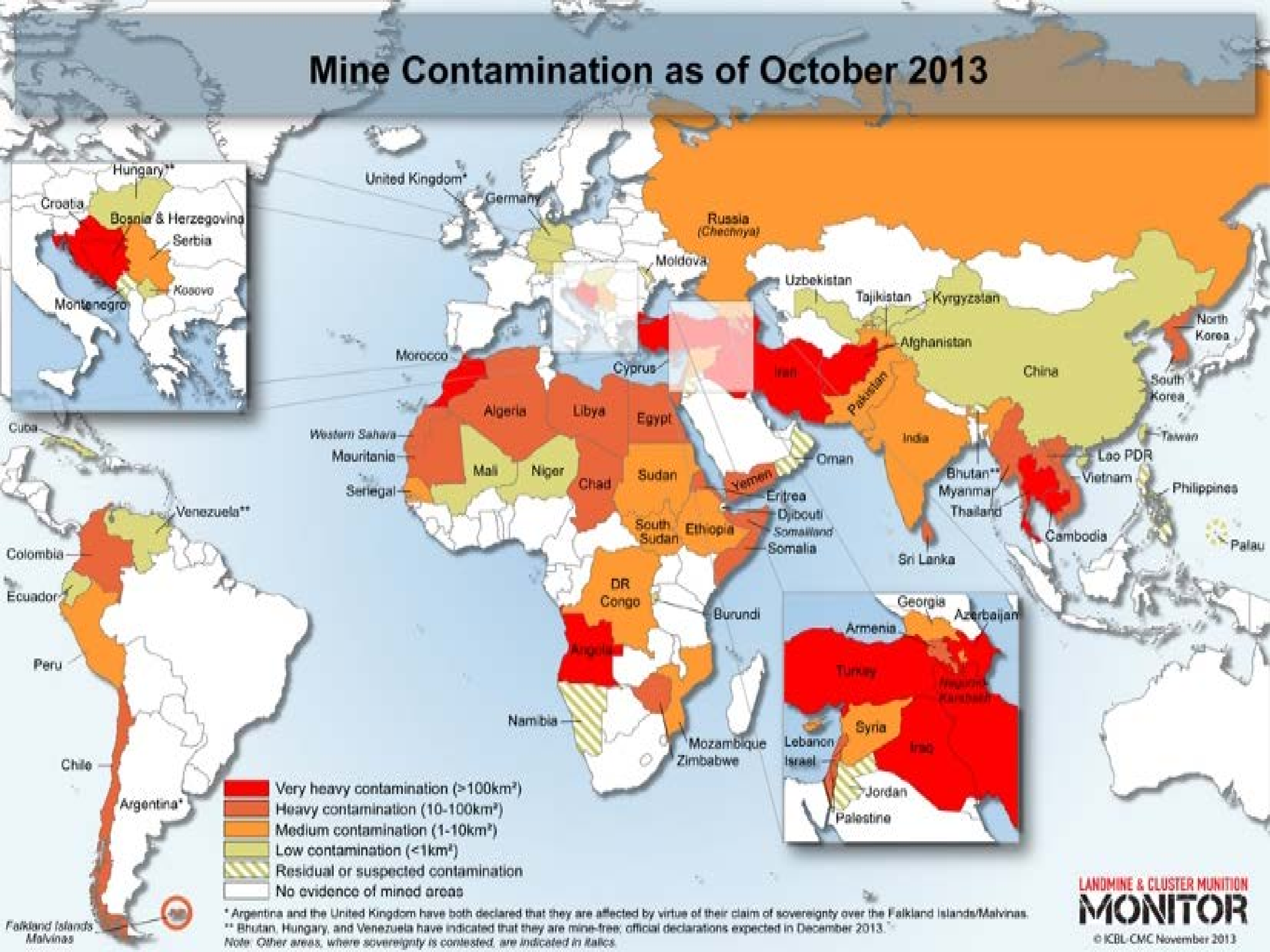
Walsh, N. E., & Walsh, W. S. (2003). Rehabilitation of landmine victims – The ultimate challenge. *Bulletin of the World Health Organization*, 81:665-670.



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Algeria
Libya
Egypt
India
Taiwan
Cuba
Western Sahara
Mauritania
Mali
Niger
Oman
Lao PDR
Bhutan**
Vietnam
Senegal
Chad
Sudan
Yemen
Eritrea
Myanmar
Philippines
Thailand
Djibouti
Venezuela**
South Sudan
Ethiopia
Somaliland
Cambodia
Palau
Colombia
Somalia
Sri Lanka
DR Congo
Ecuador
Burundi
Georgia
Armenia
Azerbaijan
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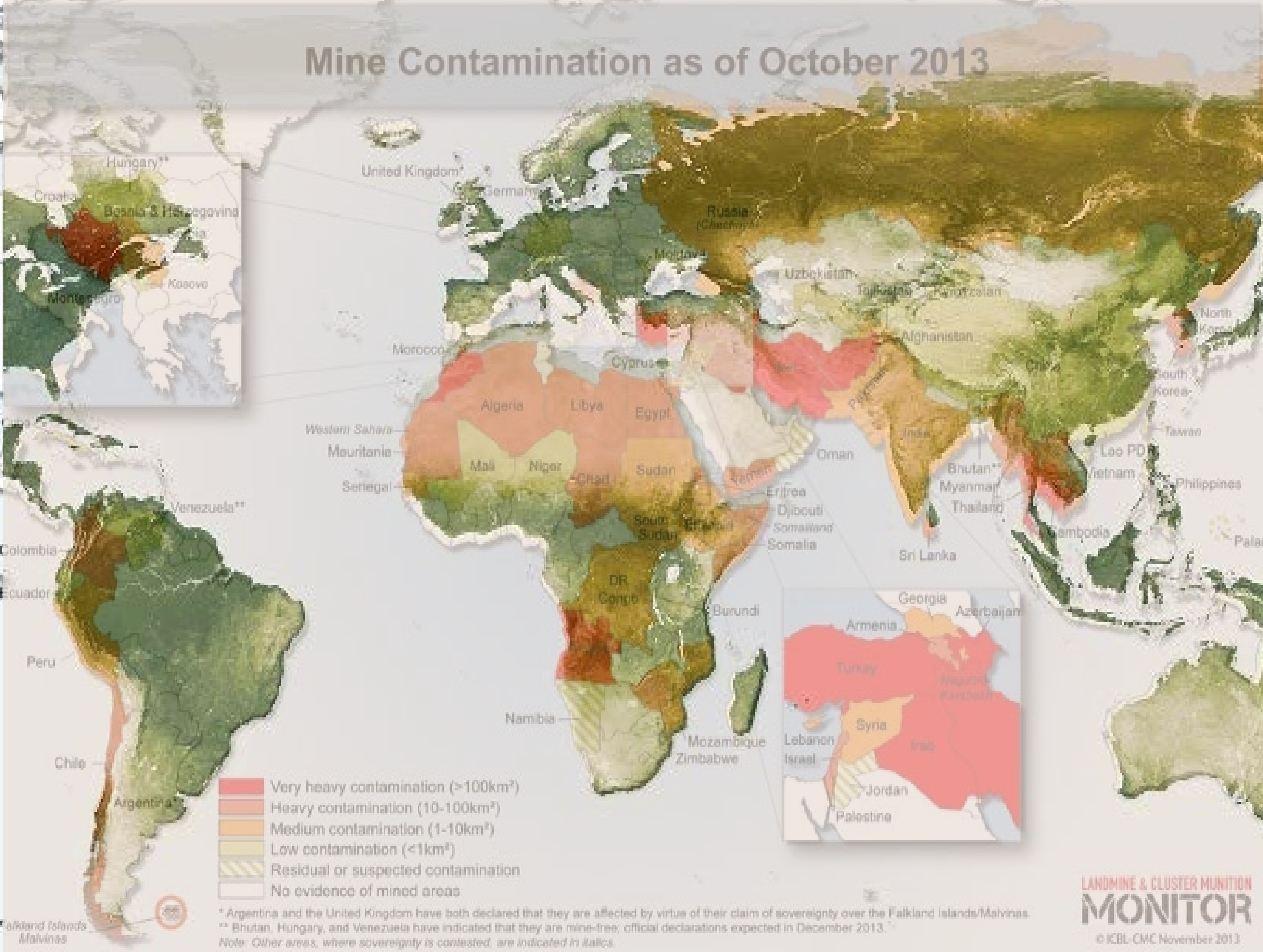
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Mali
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Chad
Sudan
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Oman
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Djibouti
Somaliland
Somalia
South Sudan
Ethiopia
DR Congo
Burundi
Namibia
Mozambique
Zimbabwe
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Thailand
Cambodia
Philippines
Palau
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Current Detection Methods

Current methods involve people in mine fields with detectors or animals

https://blogs.state.gov/stories/2017/08/22/en/us-support-mine-action-lebanon-clears-land-peaceful-use

Image courtesy of MouSensor

Current Detection Methods

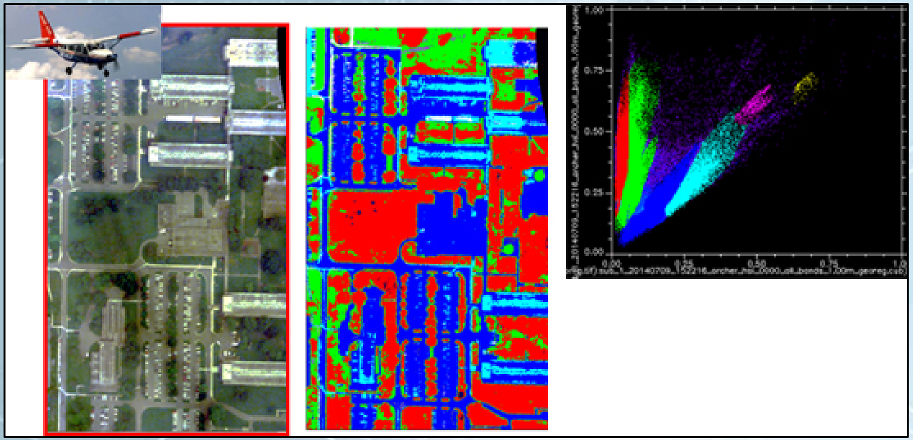
Larger equipment is also used to locate and/or detonate in place

Army Staff Sgt. Bauer Ronald, of Company B, 367th Engineer Battalion, operates an MV-4 Flail. The MV-4 is a remote-controlled mine-clearing device. Photo by Spc. Jason Krawczyk, USA. (Retrieved from http://archive.defense.gov/news/newsarticle.aspx?id=31387)

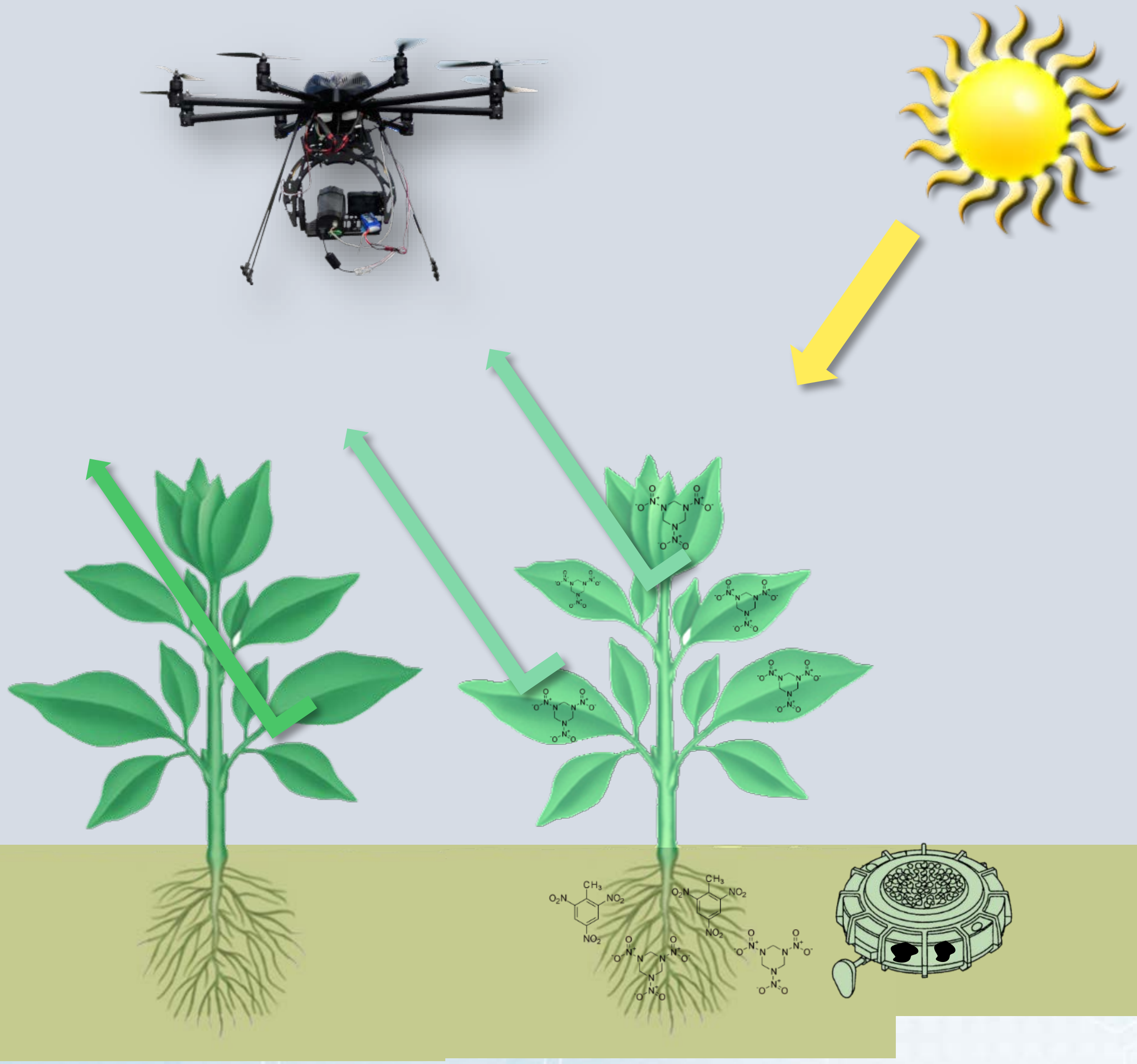
https://commons.wikimedia.org/wiki/File:Ground_Penetrating_Radar_in_use.jpg

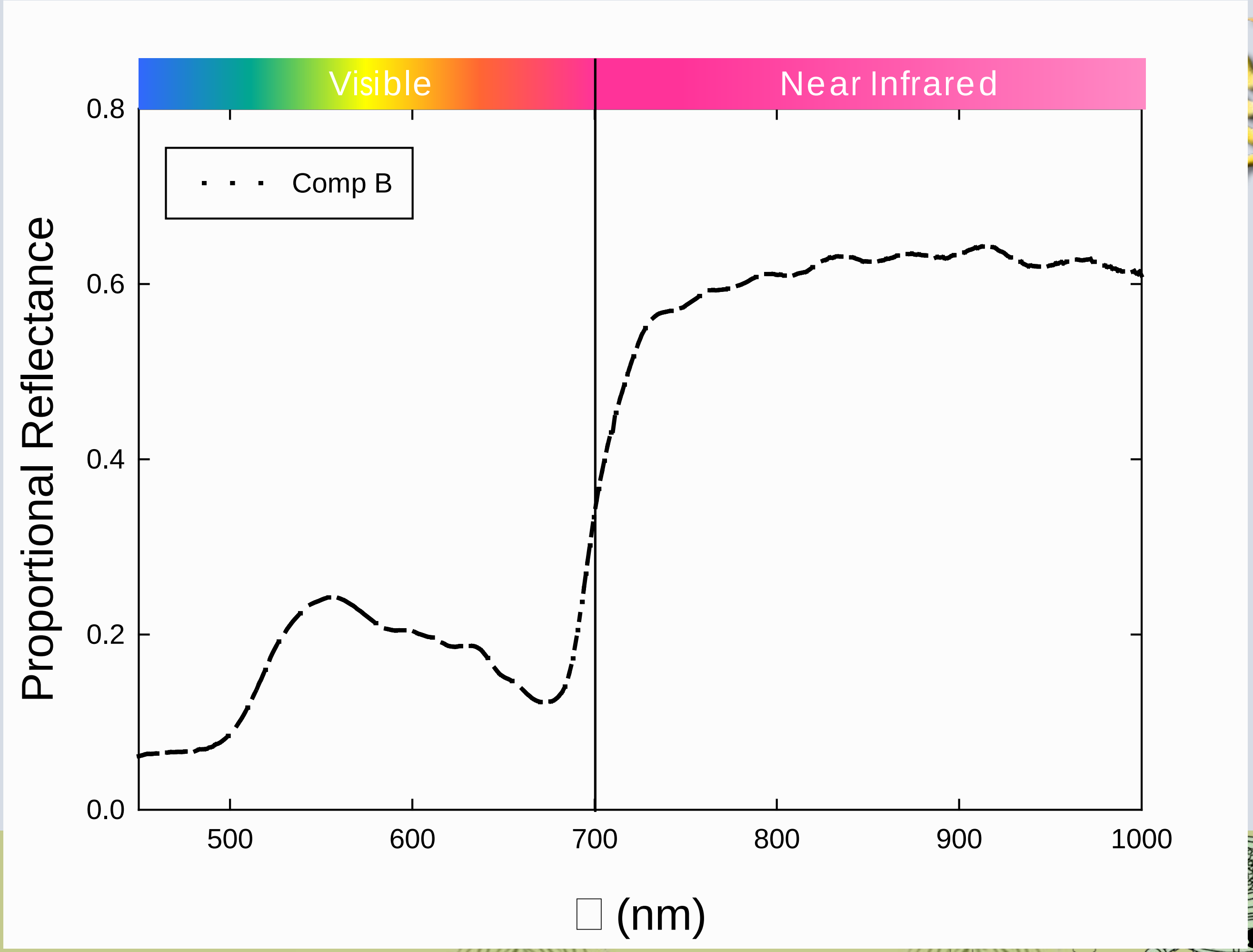
Proposed Detection Methods

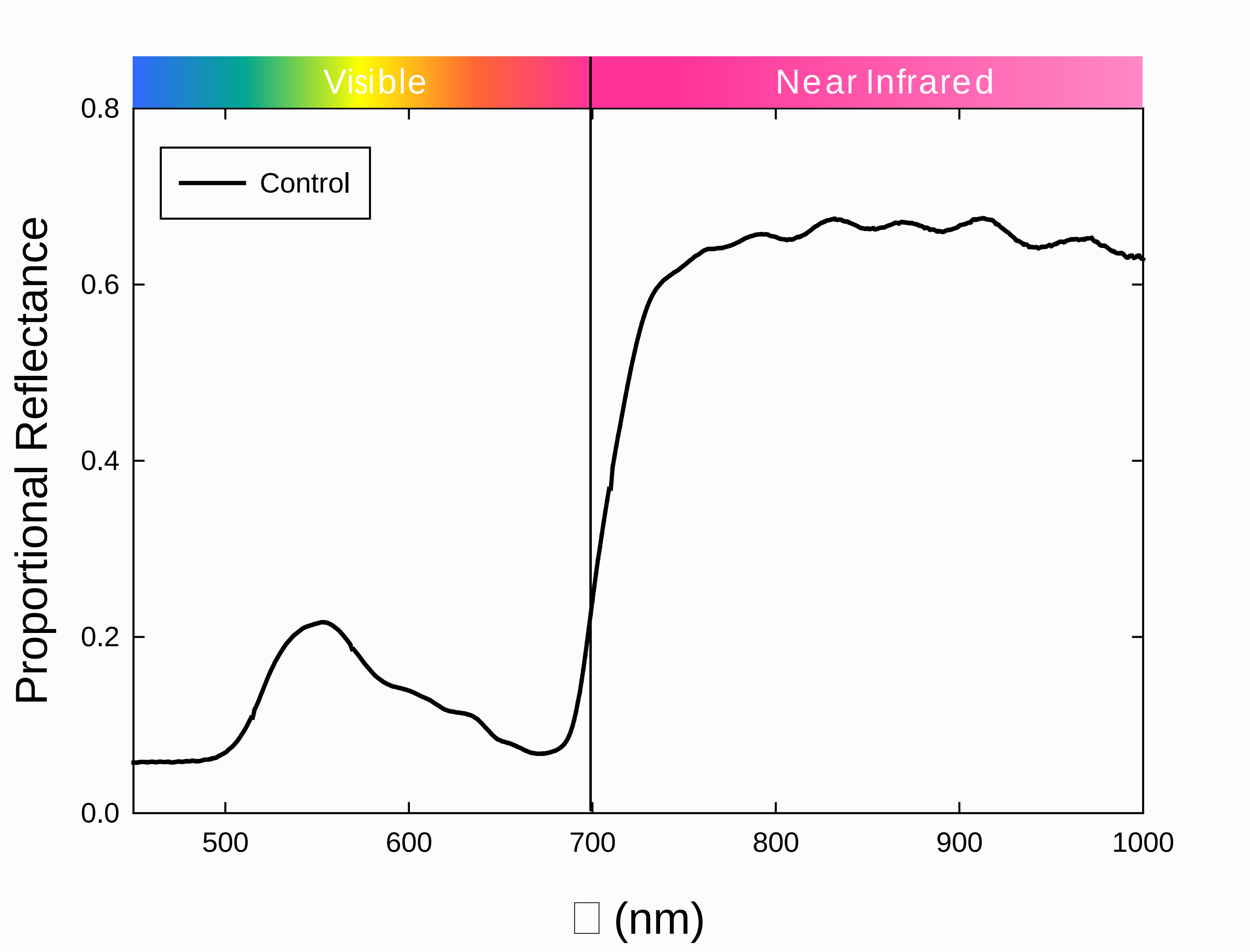
Remote sensing is a powerful tool that can use plants to uncover what lies beneath



https://www.nist.gov/programs-projects/hyperspectral-imaging-standards




Visible
Near Infrared
Comp B
Proportional Reflectance
0.0
0.2
0.4
0.6
0.8
500
600
700
800
900
1000
(nm)


Visible
Near Infrared
Control
Proportional Reflectance
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500
600
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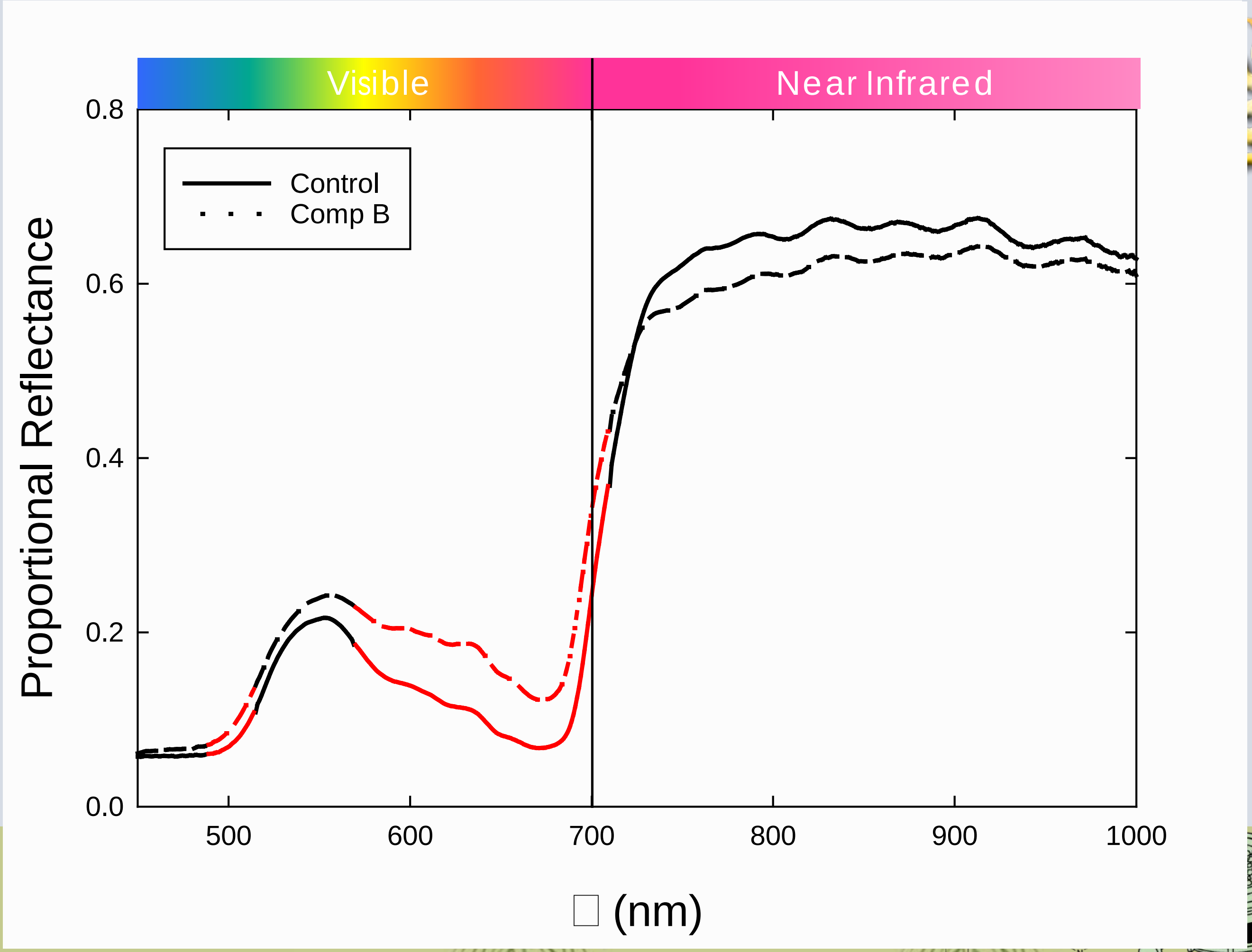
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Near Infrared
Control
Comp B
Proportional Reflectance
0.0
0.2
0.4
0.6
0.8
500
600
700
800
900
1000
□ (nm)

Methods/Materials

Species

- “Drought-susceptible” maize hybrid (AM)
- “Drought-tolerant” maize hybrid (AMX)
- Sorghum (S)
- n = 8

Treatments

- Drought
- Royal Demolition Explosive (RDX)

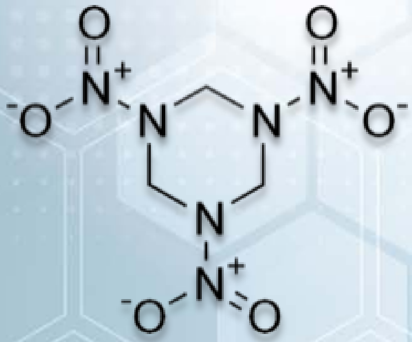
Methods/Materials

- Control groups held at 90% Field Capacity
- Drought groups held at 60% FC
- 250 mg kg^{-1} Hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX)
- RDX groups transplanted to explosive soil

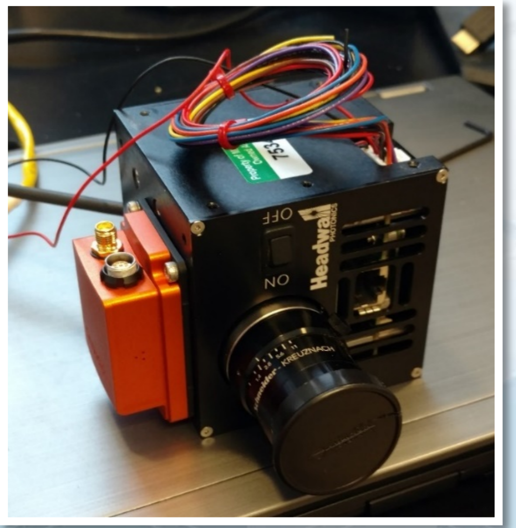
Methods/Materials

- 250 mg kg^{-1} RDX
- Weighed and dissolved in acetone
- Solution mixed with soils

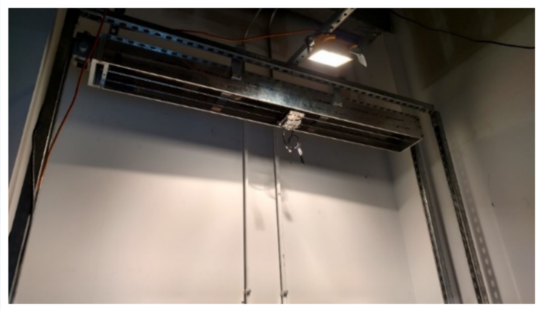
RDX

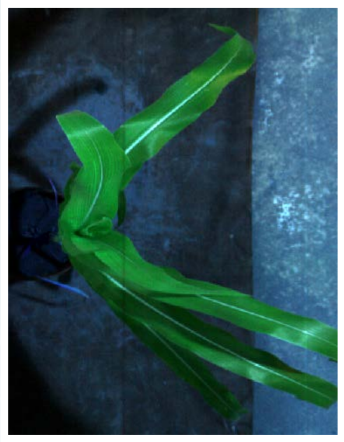


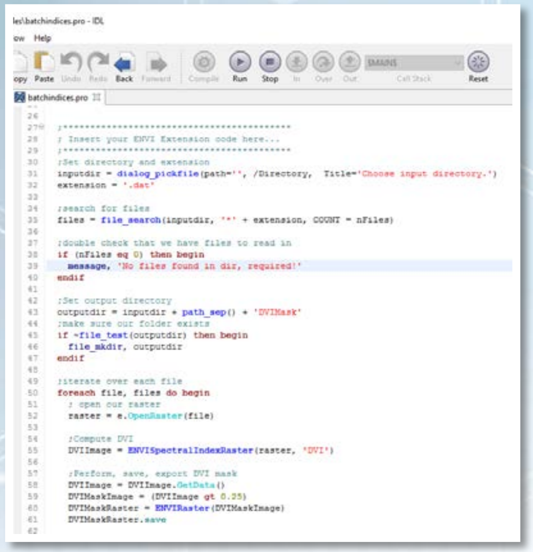
Greenhouse



- Imaged with Headwall Nano-Hyperspec
  - 400 – 1000 nm
  - Halogen light source
- Applied radiance to raw images
- ENVI + IDL used for processing







“Drought-susceptible” maize

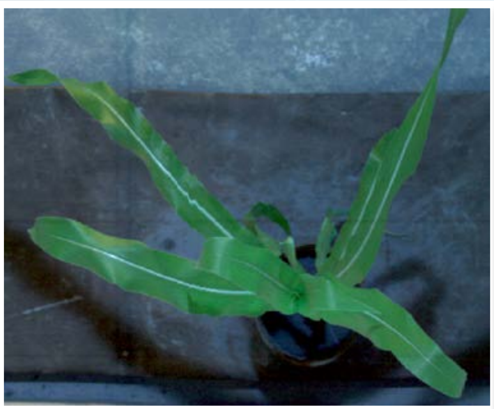
- Examples of drought-susceptible maize

Control AM | Drought AM | RDX AM

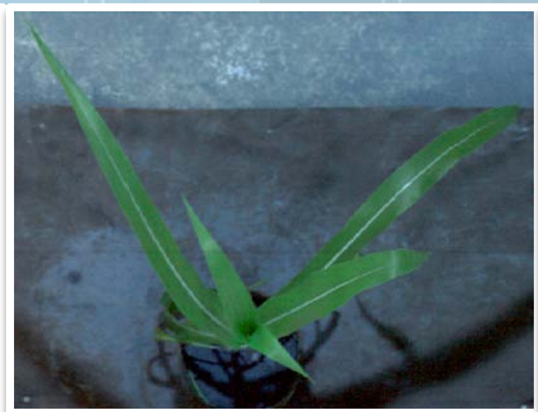
“Drought-resistant” maize

- Examples of drought-resistant maize

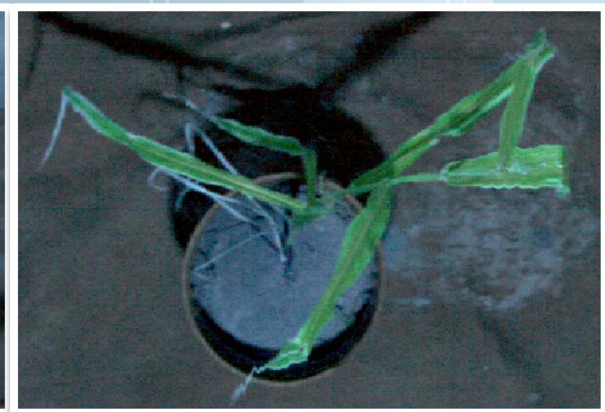
Control AM



Drought AM



RDX AM



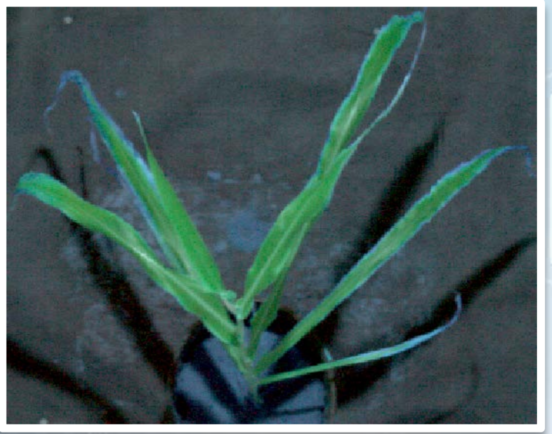
Sorghum

- Examples of sorghum

Control S

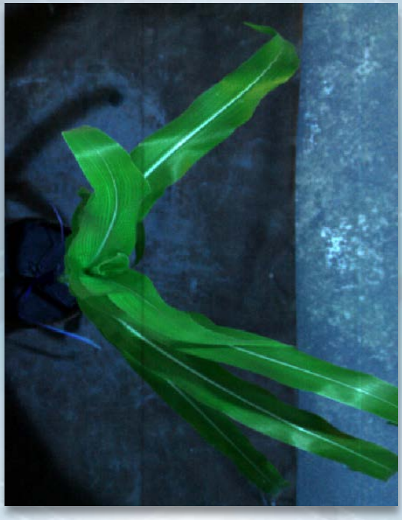
Drought S

RDX S

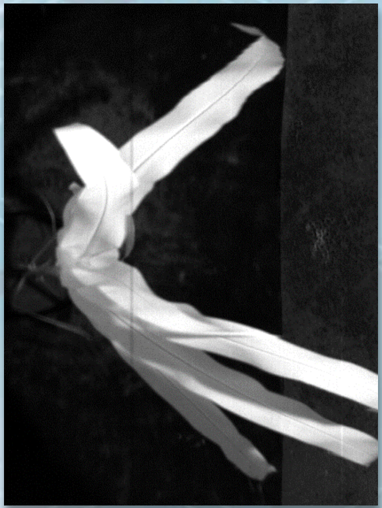


Batch processing

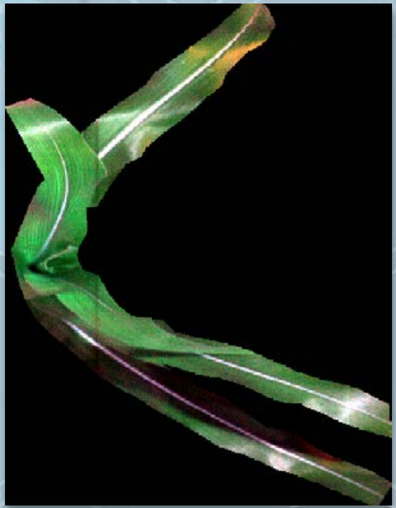
Index Averages



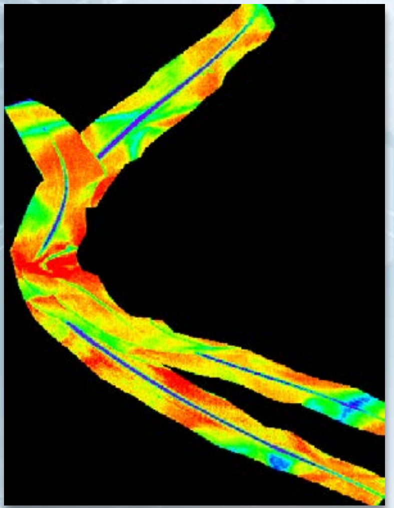
Radiometrically-corrected Maize image



Region of Interest



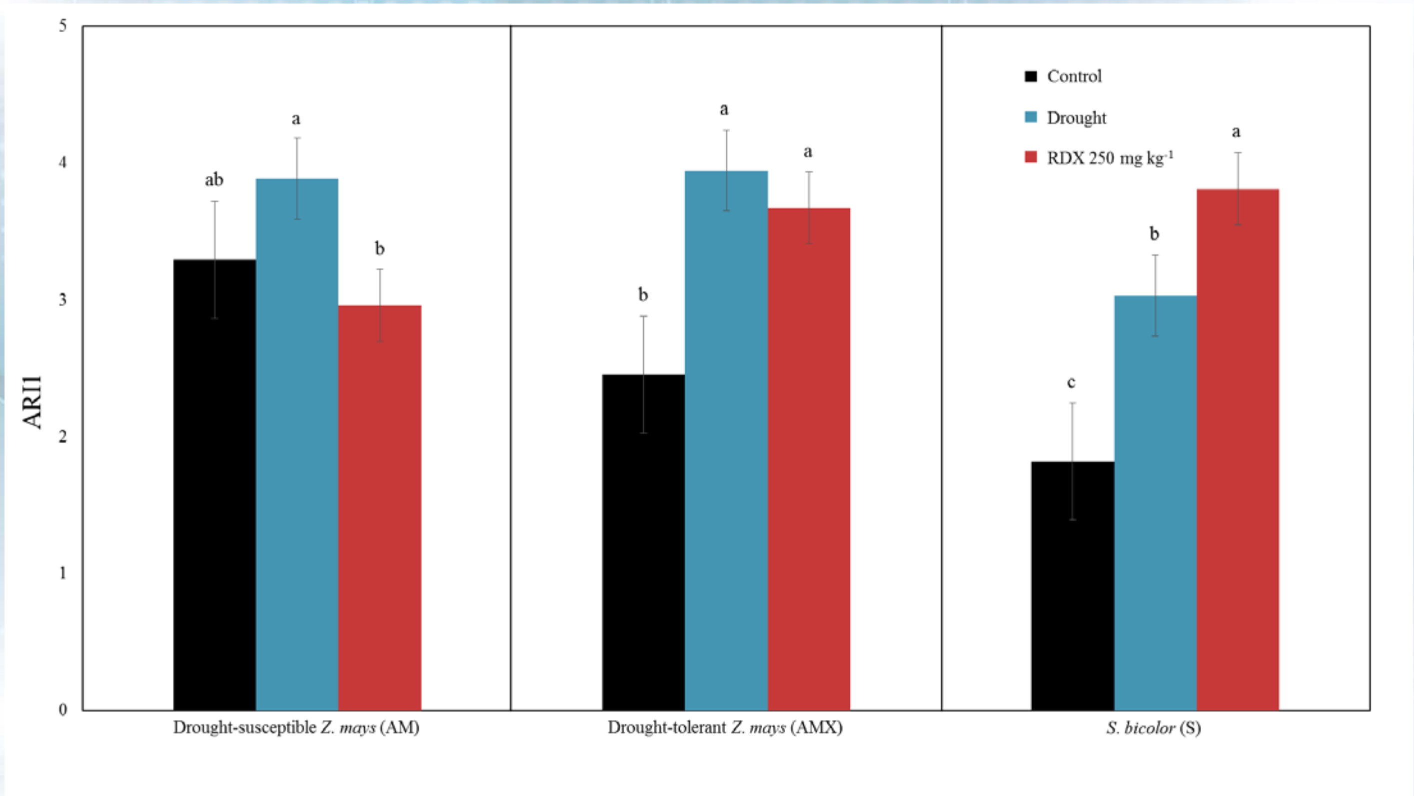
Subset



Various Reflectance Indices

Index Results

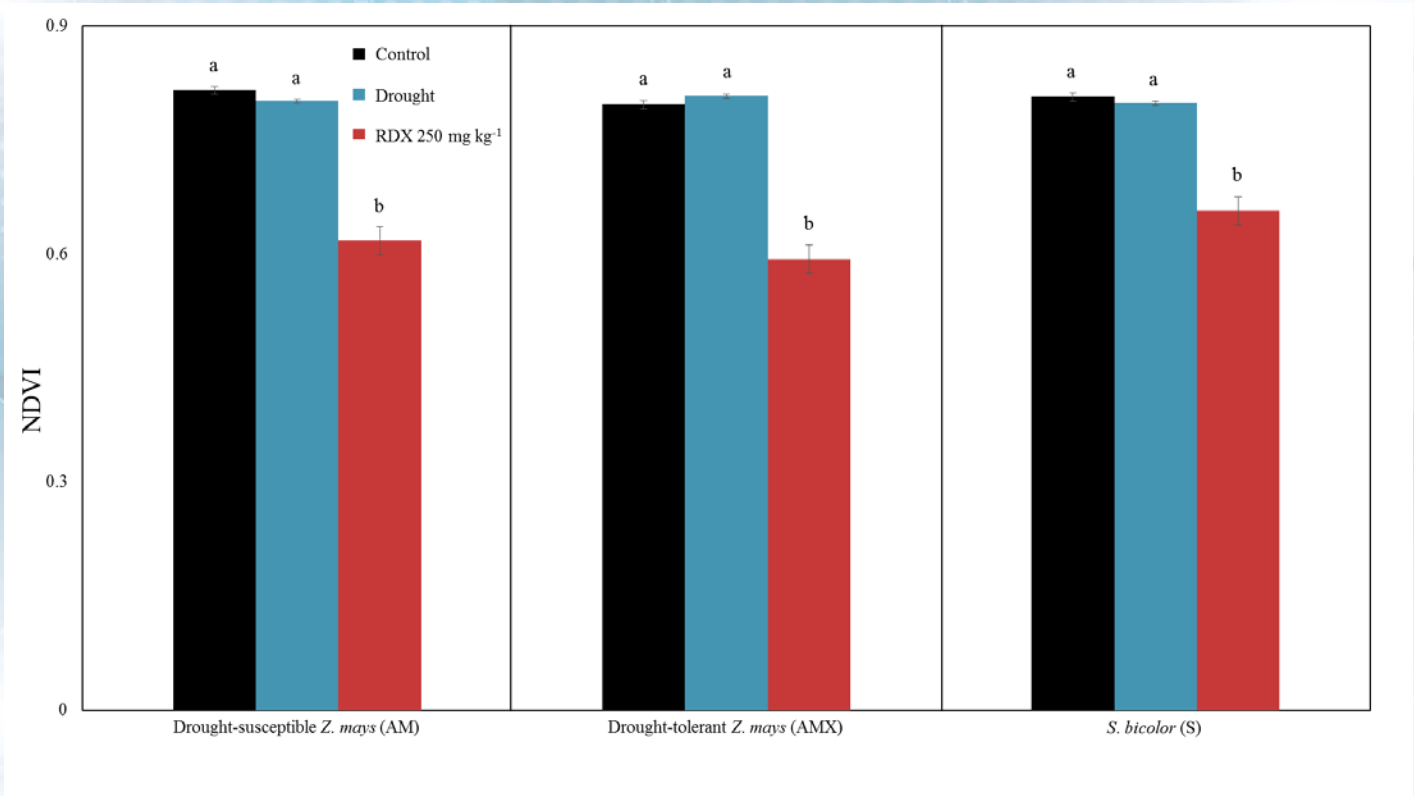
Pigments



Anthocyanin Reflectance Index 1 (stress index) – higher values indicate stress

Index Results

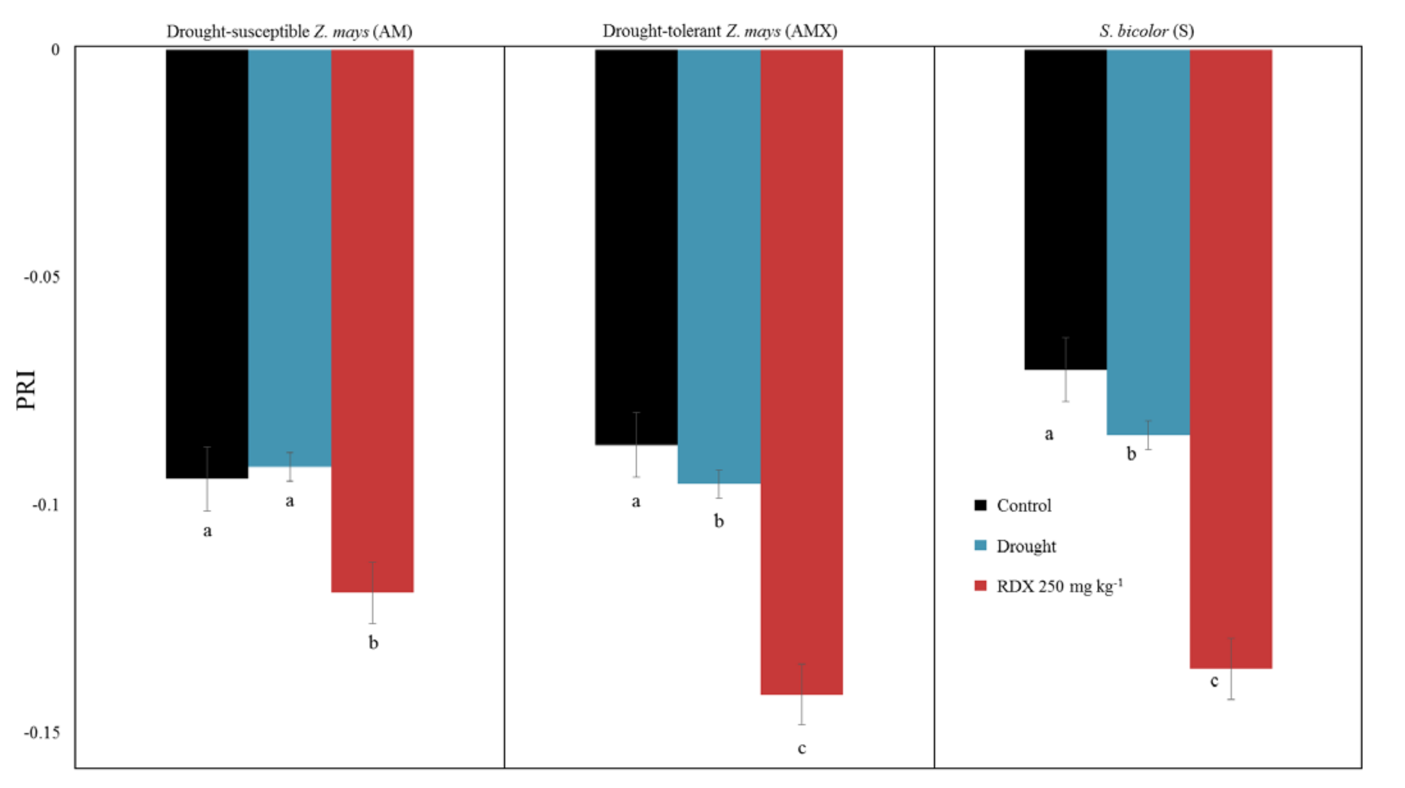
Biomass



Normalized Difference Vegetation Index – lower values indicate reductions in biomass

Index Results

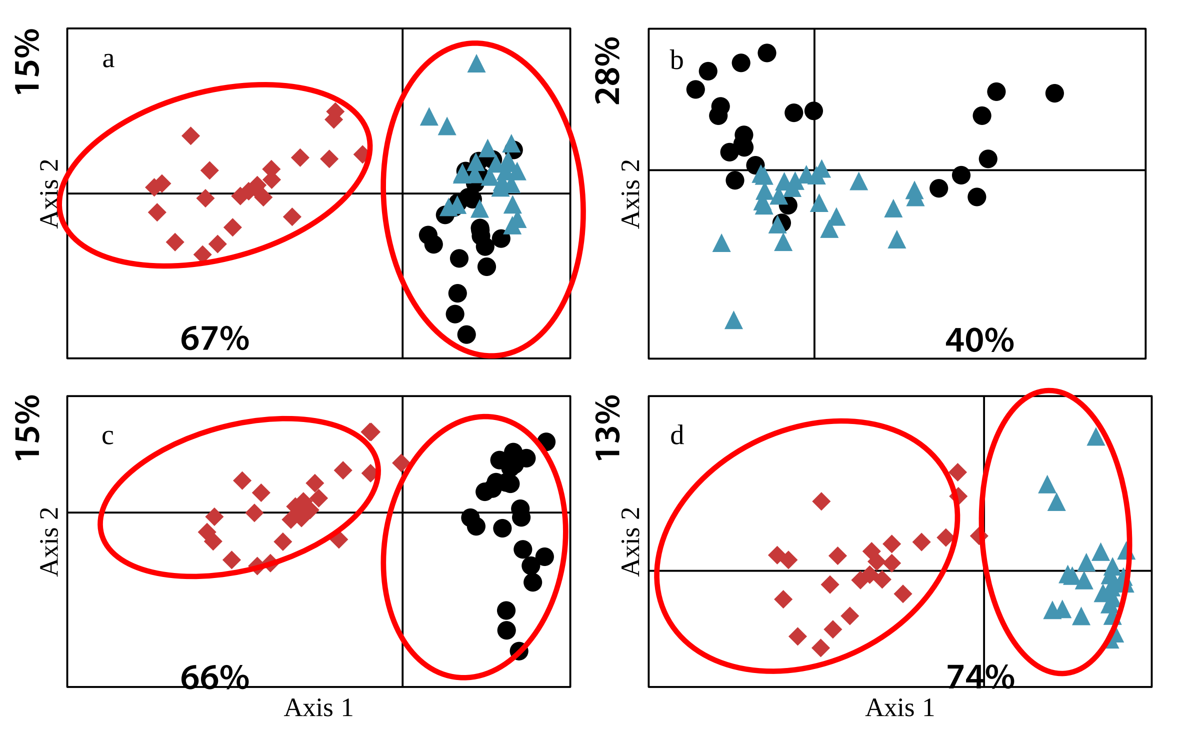
Photosynthesis



Photochemical Reflectance Index – more negative values indicate photosynthesis inhibition

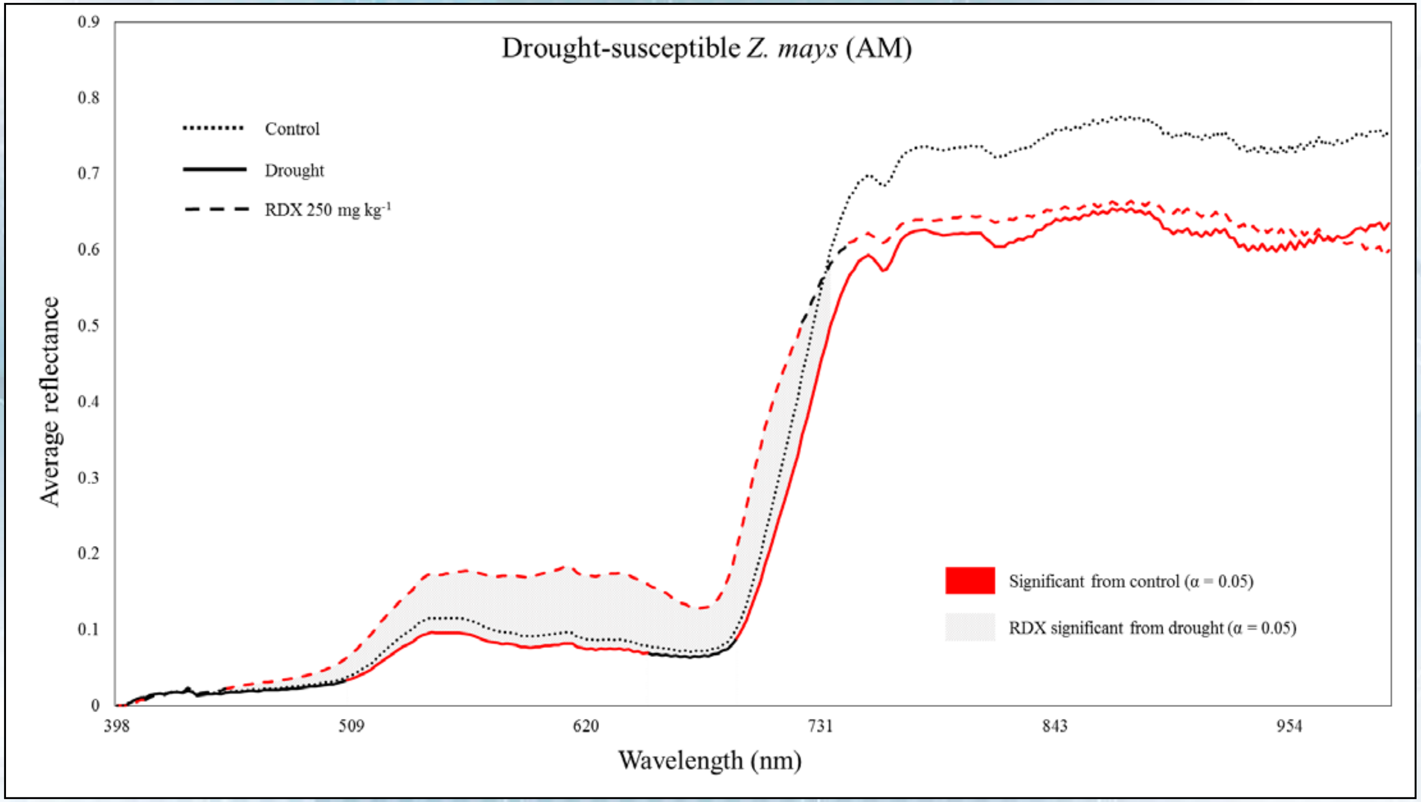
PCA Results

- Control
- Drought
- RDX 250 mg kg^{-1}



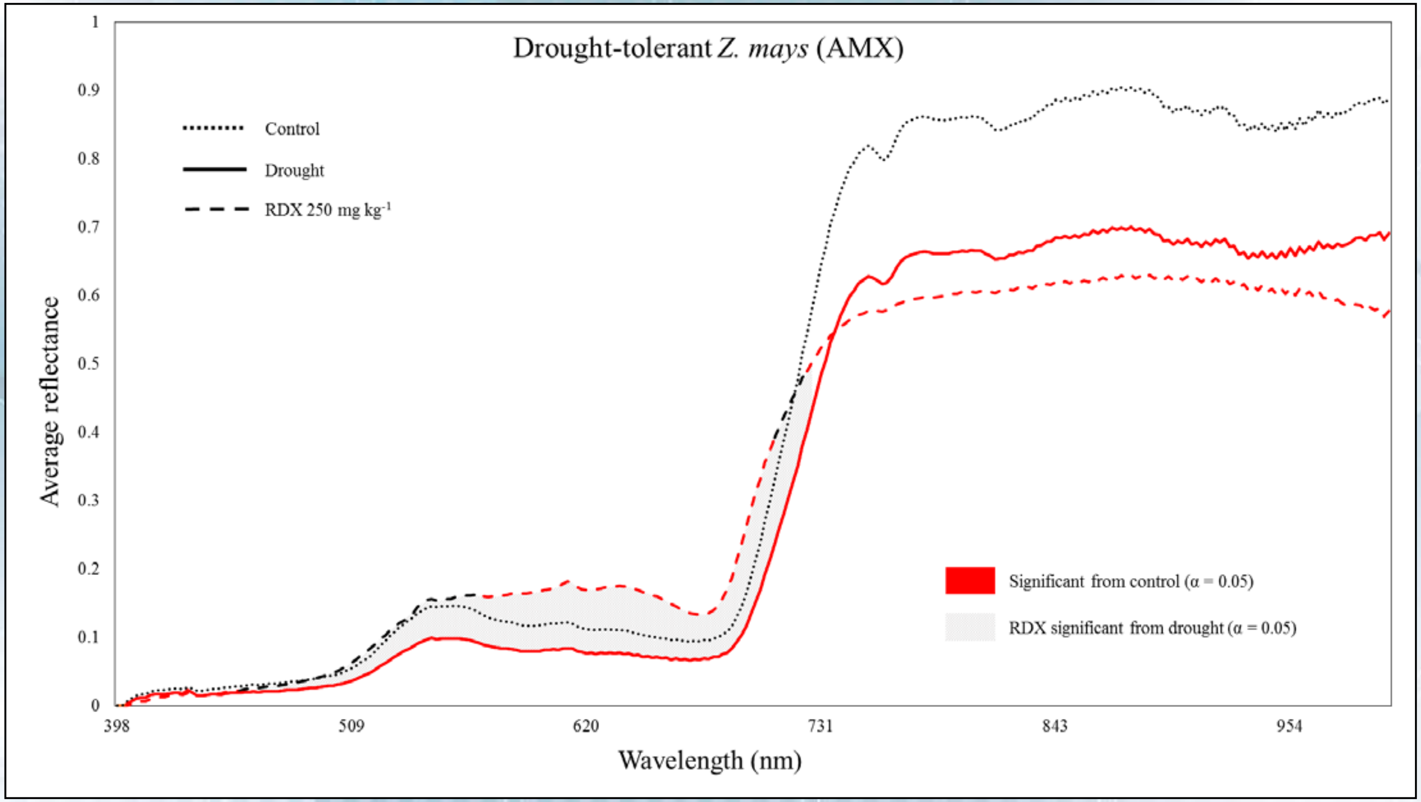
Principle Components Analyses – grouping and separation of plants treated with explosives

Spectral Profiles



Average group spectral reflectance – increased reflectance in VIS wavelengths indicate reduced pigment concentrations. Decreased reflectance in NIR indicates less biomass. “Blue shift” in red edge also a stress indicator.

Spectral Profiles



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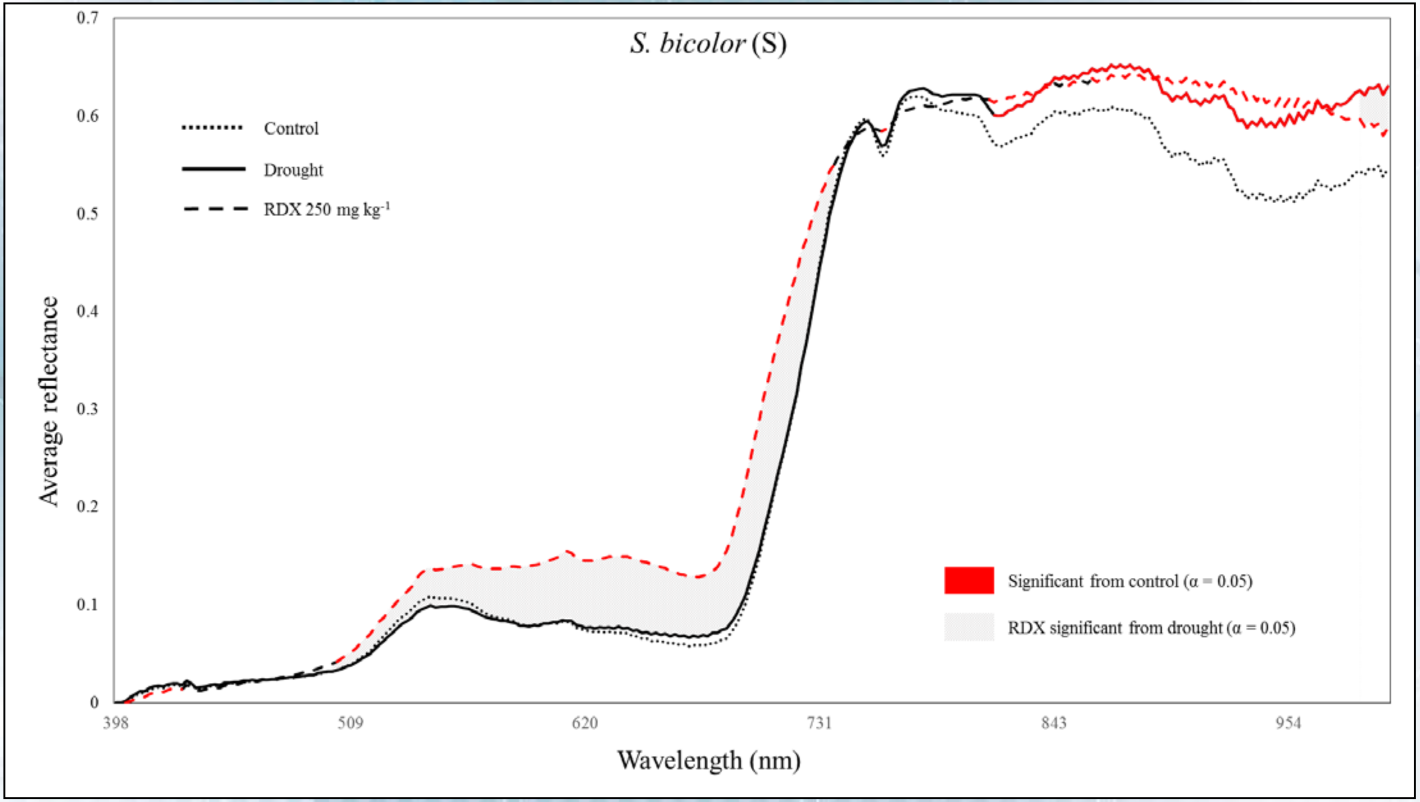
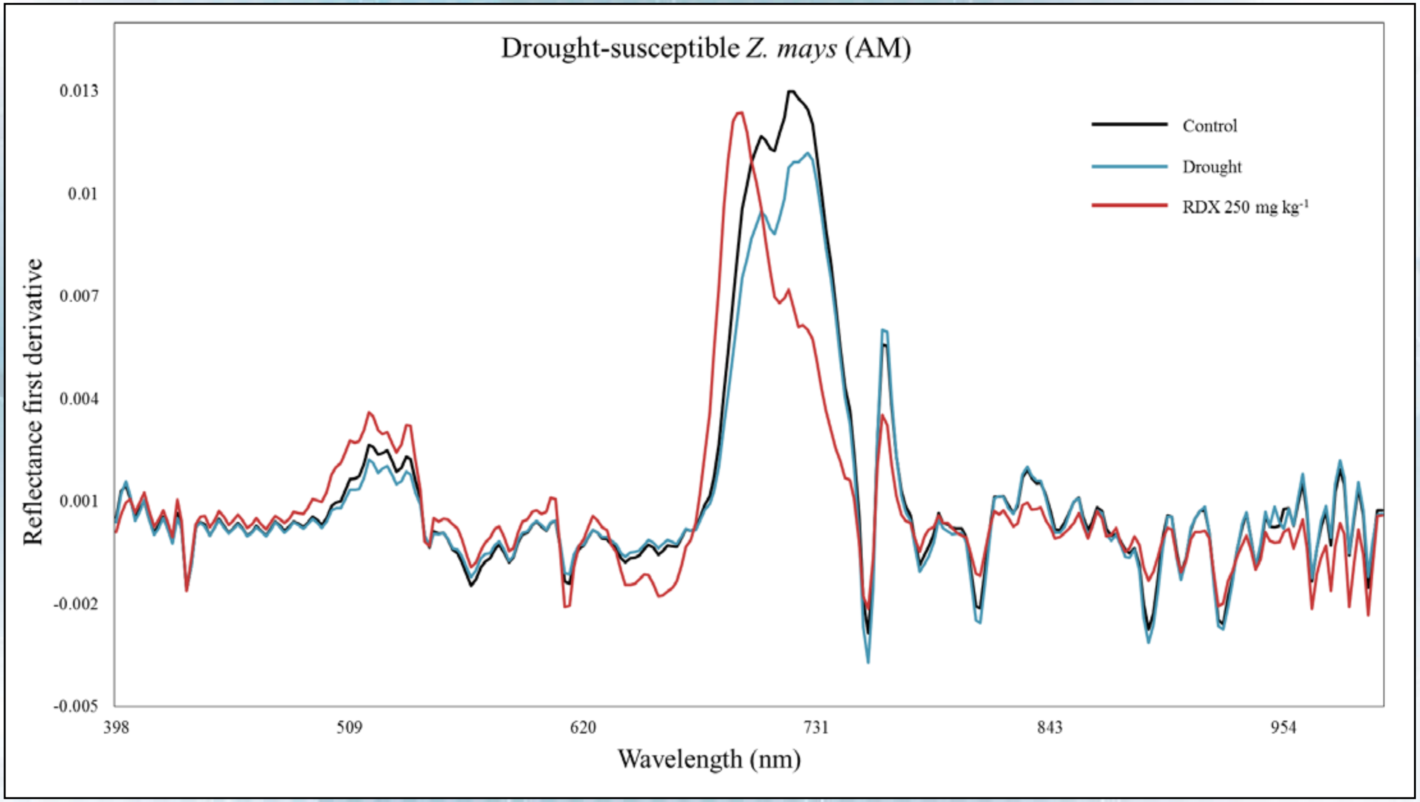
Spectral Profiles



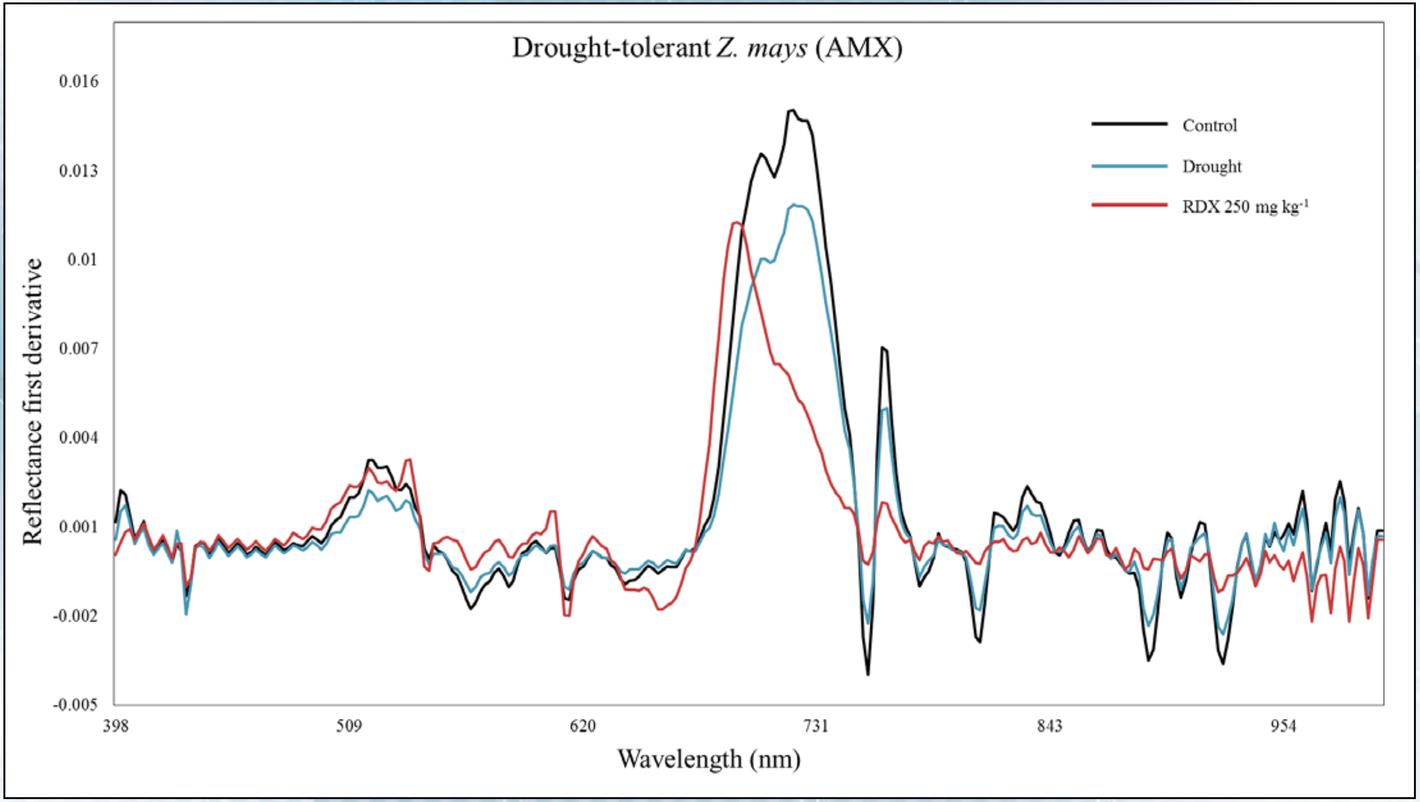
Average group spectral reflectance – increased reflectance in VIS wavelengths indicate reduced pigment concentrations. "Blue shift" in red edge also a stress indicator.

Reflectance First Derivatives



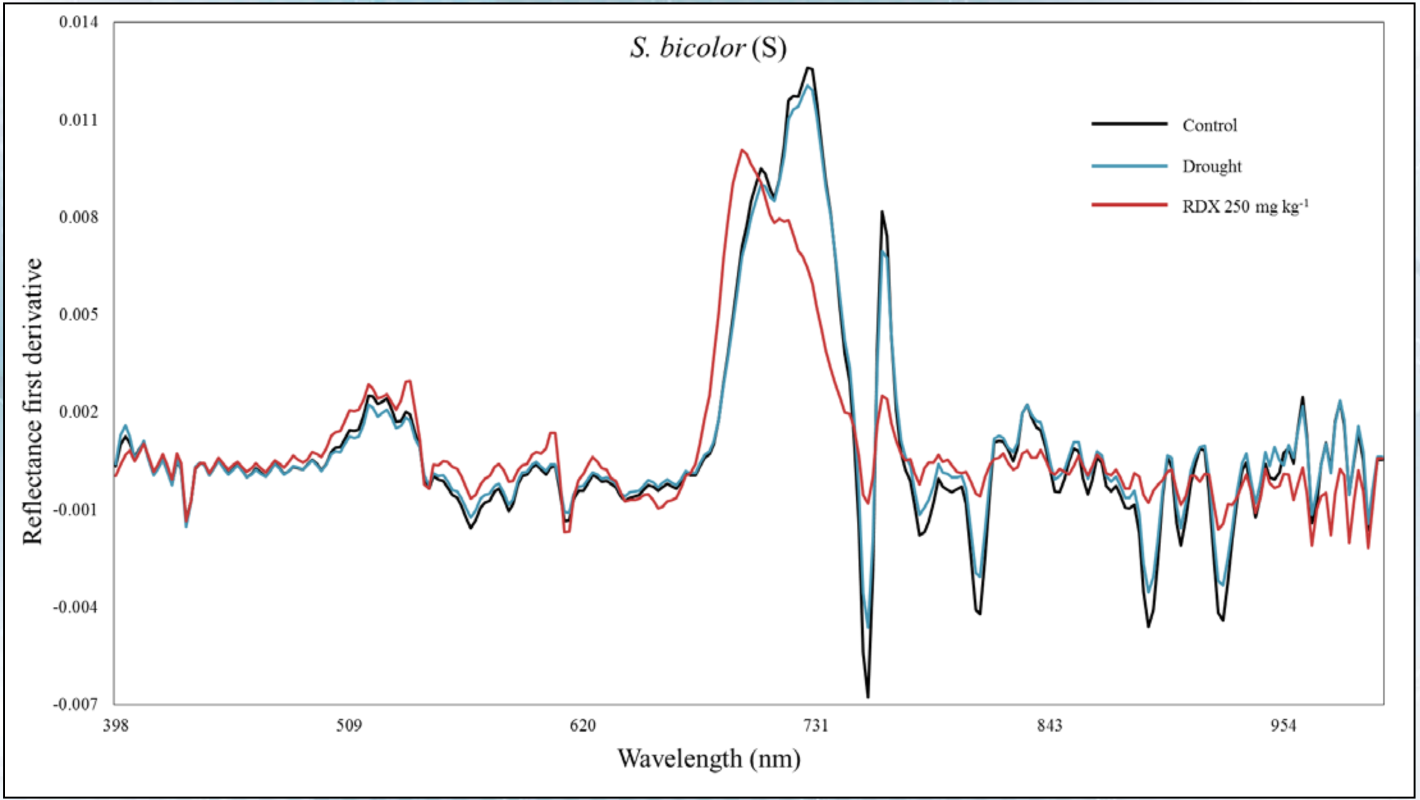
Average first derivatives of reflectance spectra. Differences indicate potential wavelengths for Explosives-Specific Index development.

Reflectance First Derivatives



Average first derivatives of reflectance spectra. Differences indicate potential wavelengths for Explosives-Specific Index development.

Reflectance First Derivatives

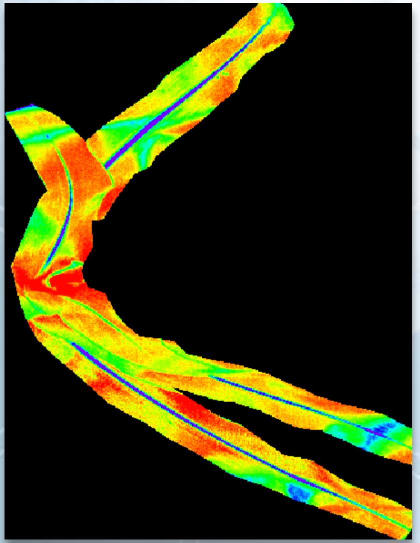


Average first derivatives of reflectance spectra. Differences indicate potential wavelengths for Explosives-Specific Index development.

Conclusion
&
Next Steps

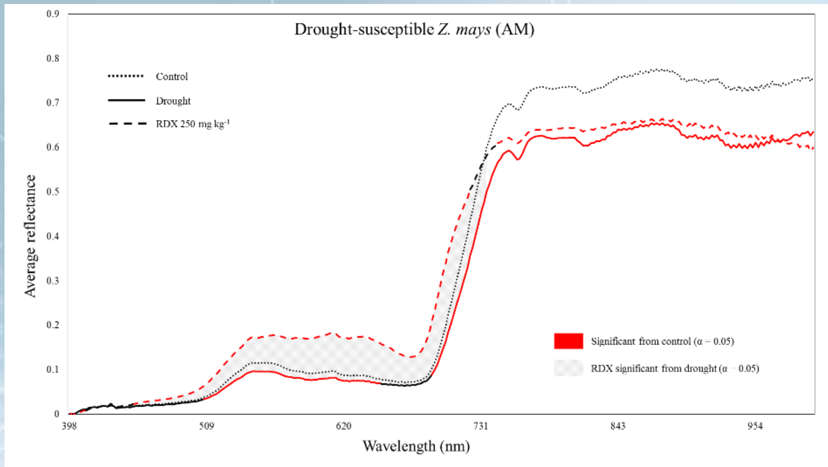
Conclusions

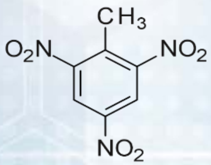
- Agricultural species respond differently to drought/explosives
- Hyperspectral imaging efficacious
- Plants are useful tools in exploring what is in subsurface
- Extra steps must be taken to strengthen link between
  - Contaminant
  - Plant exposure
  - Remote sensing



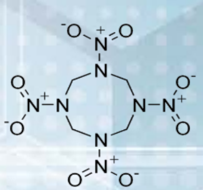
Future Work

- Broaden species
- Broaden stressors
- Scale up
- Quantify uptake
- Plant physiology
- Target wavelengths
- Index development
    - Drought
    - Explosives-specific





TNT



HMX

Select UXO Detection Methods

- Magnetometry
- Electromagnetic induction
- Ground-penetrating radar
- Infrared sensing
- Nuclear quadrupole resonance
- Vapour/fume
- Acoustic/seismic methods
- LiDAR

Andrew Louder, monitoring response geophysicist, uses a Time-Domain Electromagnetic Towed Array Detection System tool to map the subsurface at New Boston Air Force Station, N.H. Contractors are using the TEMTADS to differentiate between unexploded ordnance and cultural debris below the surface as part of a UXO clearance program at the station. Photo: Air Force Space Command, August 2013. http://www.afspc.af.mil/News/Article-Display/Article/731517/ground-piercing-radar-guides-new-boston-uxo-crews/

Key Benefits of Plants as Explosive Detectors

- **Plant-based detectors offer key capabilities, whether standalone or supplementary**
  - Ease of use promotes application beyond areas of highest concern
  - Focus on detection of explosive compounds instead of munition vessel allows for monitoring of subsurface transport
    - Useful in the long-term management of contaminated sites
  - Potential to decrease false positives when combined with conventional detection methods
  - Future ability to distinguish among different stressors (explosive compounds)

HDIAC Services

Technical Inquiry Service

- HDIAC provides up to 4 free hours of information services:
  - Literature searches
  - Document/bibliography requests
  - Analysis within our eight focus areas – Alternative Energy, Biometrics, CBRN Defense, Critical Infrastructure Protection, Cultural Studies, Homeland Defense and Security, Medical, Weapons of Mass Destruction

Core Analysis Task (CAT)

- Challenging technical problems requiring more than 4 hours of research can be solved by initiating a CAT:
  - Pre-competed and pre-awarded
  - Work can begin on a project approximately two months after the statement of work has been approved
  - Cap of $500,000 (through August 31, 2018)
  - Must be completed within 12 months

For more information: https://www.hdiac.org/technical_services

Thank You

Discussion, Questions, & Comments