Use of Remote Sensing in Potato Disease Management

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Union South – Varsity Hall I
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Precision Agriculture

A farm management concept based on observing, measuring, and responding to inter and intra-field variability to optimize inputs while preserving resources

Need disease detection and monitoring methods that are fast, accurate, non-invasive and ideally remotely sensed to realize this vision.
Impact of Disease on Potato Production

• Despite use of best and current cultivar resistance and cultural management strategies, disease negatively impacts crop yield and/or quality

• Disease can result in reduction in crop yield and/or quality during production and post-harvest

• 10-16% harvest losses each year to disease at an estimated cost of US$22 billion globally

• Pest and disease management has helped double food production in the past 40 years

Common Potato Diseases

• Late Blight – Phytophthora infestans
• Early Blight – Alternaria solani
• White Mold – Sclerotinia sclerotiorum
• Blackleg – Pectobacterium & Dickeya spp.
• Foliar & Tuber Necrotic Viruses – PVY, TRV, PMTV, PLRV
• Potato Early Dying – Verticillium dahliae & Pratylenchus penetrans
• Powdery Scab – Spongospora subterranea
• Pink Rot - Phytophthora erythroseptica
• Pythium Leak - Pythium ultimum (other spp.)
• Black Scurf - Rhizoctonia solani
• Silver Scurf - Helminthosporium solani
• Black Dot - Colletotrichum coccodes
• Fusarium Dry Rot – Fusarium sambucinum (other spp.)
• Common Scab – Streptomyces scabies (other spp.)
Common Potato Diseases – Where?

- Late Blight – *Phytophthora infestans*
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Common Potato Diseases – When?

Typical ‘disease calendar’ for northern states

<table>
<thead>
<tr>
<th>April-May</th>
<th>June</th>
<th>July</th>
<th>August</th>
<th>September</th>
<th>October</th>
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<tbody>
<tr>
<td>Rhizoctonia, Fusarium, Bacterial soft rot, Virus</td>
<td>Early blight, Blackleg, White mold, Botrytis, Brown spot, Blackleg, Virus</td>
<td>Late blight, Potato early dying, Black dot, Pink rot, Virus, Powdery scab</td>
<td>Scurfs, Black dot, Pythium leak, Late blight, Scabs, Fus, Virus, Pink rot</td>
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Infection and Disease Progress – How?

Plant response to **biotrophic pathogens** is largely programmed cell death in the host, and activation of defense responses regulated by the salicylic acid–dependent pathway.

**Necrotrophic pathogens** benefit from host cell death, so they are not limited by cell death and salicylic acid–dependent defenses, but rather by a different set of defense responses activated by jasmonic acid and ethylene signaling.

**Hemibiotrophic pathogens** utilize elements of both mechanisms.

**Hemibiotrophic pathogens:** *Phytophthora infestans*

Biotrophic pathogens: *Helminthosporium solani*

Necrotrophic pathogens: *Alternaria solani*
Means of Disease Detection in Potato

- Infected Vectors Present
- Early Stage I Isolated Plants Infected
- Early Stage II Pathogens Introduce New Plants Infected
- Late Stage III Symptoms are Noticed
- Disease Spread

Traditional Detection
- Healthy Cultivation
- Detection of Visual Symptoms

Innovative Methods
- Volatile organic compounds (VOCs and HCs)
- Gene expression changes based on metabolomic signals
- Resonance-based imaging techniques
- Spectroscopy-based methodologies
- Remote sensing technologies

ELISA
qPCR
Volatile sensors
Remote sensing
Biophotonics

Fig. 3. Comparison of methods for plant disease detection (PDD). The qualitative scores indicate: 1, poor; 2, fair; 3, good; and 4, very good. The comparison evaluates individual techniques with respect to: (1) Availability — ease of use, availability of equipment, and cost; (2) detection stage — when infections can be detected; (3) detection methods — colorimetric, ELISA, in vitro, qPCR, and biophotonics; (4) speed — time required between collection of substances and delivery of results (includes sample collection, preparation, and testing); and (5) quantification — the potential to quantify results of input data (usually carried out in a qualitative dimension, 2 data semi-quantitative, 3 data difficult to quantify, and 4 data not subject to quantification), and (6) reliability — effective accuracy of results.
Importance of early detection for late blight

- Late blight is caused by highly aggressive pathogen *Phytophthora infestans*
  - By the time scouts detect late blight in a potato field, it’s often too late to save portions of, or the entire field
- Late blight is expensive
  - Worldwide – $6.7 billion annually
  - US – $77 million spent on control
  - Despite control, losses are estimated at $288 million annually
- Disease detection before sporulation could save millions of dollars and help reduce food and seed loss caused by late blight

15 states + 2 Canadian provinces
CT, FL, MA, ME, MI, MN, NC, ND, NY, PA, VA, VT, WA, WI, WV, Manitoba, Ontario

Images from Fry et. al 2013
Late Blight in the US and WI 2017

- US-8
- US-23

Potato Late Blight
Phytophthora infestans

Sporangia on sporangiophores
Sporangia
Direct germination

Under ideal conditions, *P. infestans* can increase in population size by a factor of 300,000 every four days
Changes in plant tissues happen immediately upon infection with hemibiotroph *P. infestans*

- *P. infestans* causes a rapid change in leaf transcriptome reflecting different stages of infection
- Transcriptome changes rapidly during first seven days of infection

42 metabolites specifically increased or decreased during *P. infestans* infection (Abu-Nada, 2007)
Secondary Metabolites can be Quantified using HSR

Changes in specific wavelengths above 1600nm correspond to vibrations of chemical bonds

Based on pathogen type, different mechanisms of infection result in unique, pre-symptomatic, biochemical plant responses which can be characterized by unique spectra – are they unique enough for diagnosing specific diseases?
Light enters the leaf and is either reflected, absorbed, or transmitted. Reflected light contains a wealth of information about what’s going on at the surface and inside the leaf.

Mahlein 2016

Pathogens physically and chemically change leaf constitution. This changes both the directly and internally reflected light. We can measure reflected light using reflectance spectroscopy.

Modified from Mahlein 2016
HSR can measure specific chemical changes in plants

- HSR/HSI can measure...
  - Nitrogen content
  - Phenolic compound quantity
  - Leaf water potential
  - Vcmax (photosynthetic capacity)
- SWIR (>1300nm) wavelengths essential for understanding chemical changes

(Serbin et al. 2012, Couture et al. 2013, Townsend)
Hyperspectral Work on Plant Disease Detection

First use of HSR for disease detection. Measured hyperspectral reflectance (400-2500nm) on visibly infected plants

- Zhang 2002: Late blight on tomato

Artificial Neural Networks to accurately predict & classify healthy and diseased tomato plants with visible symptoms (<1300nm)

- Wang 2008: Late blight on tomato

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Hyperspectral Work on Plant Disease Detection

1st HS imaging for leaf changes during infection. Reflection from 400-1000nm wavelengths on visibly infected plants. Could classify differences between 3 sugar beet diseases.

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Hyperspectral Work on Plant Disease Detection

Detected powdery mildew on barley 2 days before visual symptoms with HS microscope (400-1000nm)

Developed method of observing reflectance and transmitted light simultaneously with HS microscope. Transmission gave more detailed information about internal changes

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Missing Pieces

- Previous work in HSR/I for plant disease has focused on wavelengths **below** 1000-1300nm on plants already displaying disease symptoms
  - Only one paper has examined disease **before** visual symptoms appear
- No examination of changes in spectra caused by infection before 72 hours
- No one has examined root cause of changes in spectra during infection
Research Question:
Could *Phytophthora infestans* infection be accurately detected in potato during its latent, or biotrophic, phase using hyperspectral reflectance and imaging.

**YES:** Late blight infection results in differences in SWIR spectra.
Normalized differential spectral index (NDSI) for late blight infection shows the relative differences between wavelengths most correlated with infection status.

**SWIR wavelengths are essential for differentiating infection status**

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**Late Blight**

- Infected and uninfected plants have different spectral responses at all time points—spectrometer can accurately detect late blight infection.

**Classification accuracy**

- 25% one dpi
- 55% two dpi
- 71% three dpi
- 75% four dpi

- Not detected visually until 7-10 days

**Principle Coordinate Analysis (PCoA)**

- Multivariate Distance Scaling (MDS)
- Visualization of inter-object dissimilarity in Euclidean space
- Principle Component Analysis (PCA) then conducted to capture as much variation as possible on main two axis.
Late Blight

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Summary

- Late blight can be detected before visual symptoms appear in highly and less conducive disease environments
  - 2-3 days pre-symptoms in favorable conditions
  - 4-5 days pre-symptoms in less favorable conditions
- *P. infestans* can be detected during the biotrophic phase
  - >80% accuracy 24 hours post inoculation
  - 93% accuracy 36 hours post inoculation
  - 85% across all time points in the study
- Specific NDSIs can be linked to changes in *P. infestans* life cycle
  - Biotrophic growth is characterized by changes in the NIR
  - Lesion formation and sporulation is characterized by changes in the SWIR
- Future experiments will involve model validation, field studies, and investigations into underlying biochemical causes
- Early blight was also detected with 60% accuracy at 24 hpi
Common Potato Diseases – more work to be done!

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Towards a spectra-based predictive model rooted in *P. infestans* biology – see Katie Morey Gold poster at 3:30PM session today
Acknowledgements

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Questions?