ICPP 2023

ONE HEALTH for all plants, crops and trees

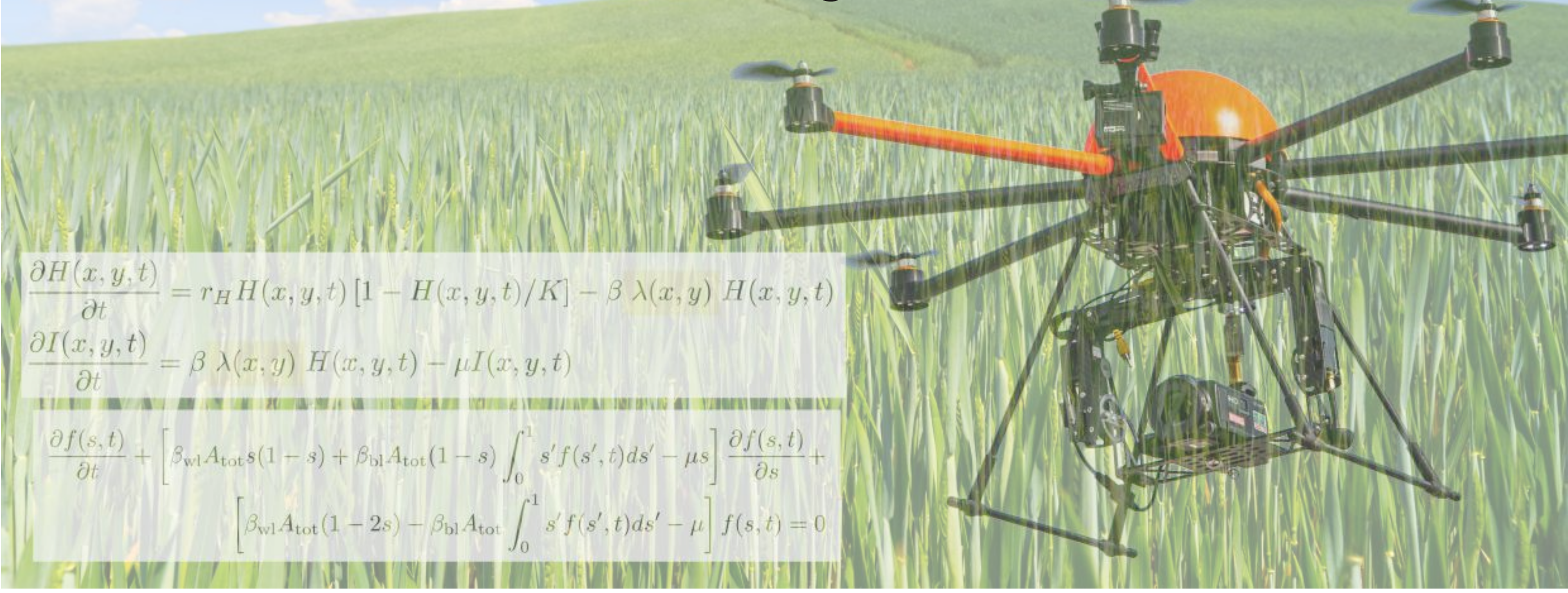
LYON

20-25 August, France

satellite event

How to combine remote sensing with epidemiological modelling to improve plant disease management?

19th-20th August 2023



$$\frac{\partial H(x,y,t)}{\partial t} = r_H H(x,y,t)\left[1 - H(x,y,t)/K\right] - \beta\ \lambda(x,y)\ H(x,y,t)$$

$$\frac{\partial I(x,y,t)}{\partial t} = \beta\ \lambda(x,y)\ H(x,y,t) - \mu I(x,y,t)$$

$$\frac{\partial f(s,t)}{\partial t} + \left[\beta_{\mathrm{wl}} A_{\mathrm{tot}} s(1-s) + \beta_{\mathrm{bl}} A_{\mathrm{tot}}(1-s)\int_0^1 s' f(s',t) ds' - \mu s\right]\frac{\partial f(s,t)}{\partial s} + \left[\beta_{\mathrm{wl}} A_{\mathrm{tot}}(1-2s) - \beta_{\mathrm{bl}} A_{\mathrm{tot}}\int_0^1 s' f(s',t) ds' - \mu\right] f(s,t) = 0$$

British Society for Plant Pathology BSPP

SFP

Mod Stat SAP
Réseau de recherche
Modélisation et statistique en santé des animaux et des plantes

INRAE

How to combine remote sensing with epidemiological modelling to improve plant disease management?

Recent technological advances suggest that plant diseases can be detected early – at various spatial scales – using remote sensing. This offers the possibility of revolutionising our understanding of plant pathogen interactions.

Remote sensing is a rapidly growing research field. There is also a large existing research community focused on plant disease epidemiology and modelling. However, and with some notable exceptions, few researchers concentrate on using remote sensing for plant diseases.

This satellite meeting is therefore intended to link two – currently largely disjoint – research communities. We have aimed to bring together plant disease modellers and those interested in remote sensing. Our schedule contains some talks very firmly on one topic or the other, as well as some explicitly on the interface. We hope that our conference programme – and the associated opportunities for networking – leads to a range of fruitful interactions.

As well as linking the two communities, a goal of the meeting is to write a "*Challenges in…*" review article, highlighting what progress has been made, and what remains to be done. Thank you for sending us your thoughts on key challenges in advance of the meeting. We will spend time during the first day presenting a synthesis of what emerged and have built time into the programme for discussion in break out groups. We hope to be able to assign writing tasks at the end of the meeting, aiming to be able to submit a manuscript by the end of the year.

We are all very much looking forward to a stimulating and exciting meeting.

Organising committee. Alexey Mikaberidze (University of Reading, UK), Carlos Camino (EC JRC, Italy), Frédéric Fabre (INRAE, France), Frédéric Hamelin (Institut Agro, France), Nik Cunniffe (University of Cambridge, UK), Pieter Beck (EC JRC, Italy), Stephen Parnell (University of Warwick, UK) and Suzanne Touzeau (INRAE, France).

Thanks. This satellite event would not have been possible without generous funding provided by BSPP (British Society for Plant Pathology), SFP (Société Française de Phytopathologie), INRAE (Plant Heath & Environment division, Mathematics & Digital Technologies division and ModStatSAP, the research network in Modelling and Statistics for Animal and Crop Health).

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TIMETABLE

Day One. Saturday 19th August 2023

SESSION ONE. INTRODUCTION & DIDACTIC TALKS (11am – 12.30pm) *[Rapporteur = Frédéric Fabre]*

10.30	COFFEE WILL BE AVAILABLE BEFORE THE MEETING STARTS		
11.00	The organisers		Welcome
11.05	A. Mikaberidze N. Cunniffe	U. Reading, UK U. Cambridge, UK	Epidemiological modelling and the Basic Reproduction Number, R_0
11.45	U. Rascher	U. Bonn, Germany	Measuring plant structure and function using optical remote sensing[1]

LUNCH (12.30pm – 1.30pm)

A packed lunch will be provided

SESSION TWO. KEYNOTE TALKS (1.30pm – 5.15pm) *[Rapporteur = Suzanne Touzeau]*

1.30	K. Gold	Cornell U., USA	Harnessing remote sensing and imaging spectroscopy for agricultural disease management
2.15	S. Soubeyrand	INRAE, France	Estimating Beet Yellows severity at plot resolution with satellite observations
3.00	COMFORT BREAK		
3.10	Poster authors		Flash talks (up to 2.5 minutes each) on posters
3.50	The organisers		Brief introduction to review article: challenges in combining remote sensing with epidemiological modelling
4.00	COFFEE BREAK		
4.30	P. Zarco-Tejada	U. Melbourne, Aus.	High-resolution hyperspectral and thermal imaging for the early detection of plant diseases

POSTER SESSION (5.30pm – 6.30pm)

Poster presentations and networking

DINNER (8pm onwards)

Attendees who have signed up to join the organising committee and invited speakers for dinner are reminded our table is booked for 8pm

[1] Titles of some talks are slightly abridged in this table; full titles are given later in this booklet.

Day Two. Sunday 20th August 2023

SESSION THREE. CONTRIBUTED TALKS (9.30am – 12.30pm) *[Rapporteur = Frédéric Hamelin]* (S = Shorter 15-minute presentation)

9.30	S. Fraser	Scion, NZ	Combining remote sensing and epidemiological modelling to improve management of red needle cast
9.50	V. Rossi[2]	UCSC, Italy	Can remote sensing data improve mathematical models for tactical decision making & fungicide application?
10.10	R. Calderon	Cornell U., USA	Mapping global risk of fusarium wilt in a changing climate with remote sensing and aerosol transport modelling
10.30	COFFEE BREAK		
11.00	M. McMenemy	U. Strathclyde, UK	An epidemiological model to assess the efficacy of monitoring technologies for early detection
11.20	M. Günder	U. Bonn, Germany	Combining data and knowledge for disease spread modelling and simulation shown for *Cercospora* leaf spot
11.40	C. Cruz[3]	Purdue U., USA	Integrating UAS-based multispectral imaging and epidemiological modelling in cereal crops
12.00	M. Leclerc	INRAE, France	Combining imaging and spatially explicit modelling for the study of plant diseases (S)
12.15	R.Darvishzadeh[4]	U. Twente, Neth.	Understanding fall armyworm infestation in maize fields of Bangladesh using temporal Sentinel-2 data (S)

LUNCH (12.30pm – 1.30pm)

A packed lunch will be provided

SESSION FOUR. FURTHER CONTRIBUTED TALKS & DISCUSSION OF REVIEW ARTICLE (1.30pm – 5.30pm) *[Rapporteur = Stephen Parnell]*

1.30	J. Ellis	U. Cambridge, UK	A modelling approach to map the risk of HLB in the Iberian Peninsula (S)
1.45	R. Campbell	Plant & Food, NZ	Disease climatic risk model interpretations at multiple spatial scales (S)
2.00	D. Lee	POSTECH, Korea	The utility of proximal sensing and deep learning in the detection and characterization of Tar Spot (S)
2.15	R. Trimble	U. Cambridge, UK	Integrating reinforcement learning & epidemiological models for control optimisation with limited information (S)
2.30	C. Camino	EU JRC, Italy	Quantifying Vcmax & plant traits to monitor forest decline by satellite images & biophysical models (S)
2.45	S. Delalieux	VITO, Belgium	Remote sensing in support of plant disease detection at different spatial scales (S)
3.00	COMFORT BREAK		
3.10	The rapporteurs		Brief synthesis of all sessions & orientation for breakout sessions
3.25	All attendees		First breakout session (30 minutes of discussion + 5 minutes to summarise)
4.00	COFFEE BREAK		
4.15	All attendees		Second breakout session (30 minutes of discussion + 5 minutes to summarise)
4.50	All attendees		Open discussion
5.00	The organisers		Further discussion of review article, and selection of section lead authors

[2] The first author of the talk presented by V. Rossi is G. Fedele.
[3] The first author of the talk presented by C. Cruz is C. Gongora-Caul.
[4] The first author of the talk presented by R. Darvishzadeh is T. Dzurume.

ORAL PRESENTATIONS

Abstracts for the oral presentations tabulated below are given in the subsequent pages.

[5] The first author of the talk presented by V. Rossi is G. Fedele.
[6] The first author of the talk presented by C. Cruz is C. Gongora-Caul.
[7] The first author of the talk presented by R. Darvishzadeh is T. Dzurume.

EPIDEMIOLOGICAL MODELLING AND THE BASIC REPRODUCTION NUMBER, R_0

MIKABERIDZE A. (1), CUNNIFFE N. (2)

(1) University of Reading, Reading, UNITED KINGDOM; (2) University of Cambridge, Cambridge, UNITED KINGDOM

Initial modelling work for plant diseases was highly distinctive. However, commonalities with parallel work focusing on pathogens of humans and animals have gradually been recognized. Recent work has therefore tended to concentrate on compartmental models, which are now the dominant theoretical paradigm for plant epidemic modelling. The Basic Reproduction Number – the average number of infections expected from the introduction of a single infectious individual into a totally susceptible population – is a key unifying concept. It promises much in summarizing via a single intuitive metric the ability of a pathogen to spread, as well as the likely utility of any disease management. However, many aspects of plant disease are distinctive – the large effect of host spatial structure, infection rates that are highly dependent on environmental conditions, and complex heterogeneities in the availability of hosts for infection in both space and time – and this requires adaptation. Recent trends to include stochasticity in models also suggest that a metric focused so closely on population level averages might omit important aspects of behaviour. In this didactic talk we introduce how the Basic Reproduction Number can be calculated for a range of model structures relevant to plant disease and discuss the challenges of applying the concept specifically to plant pathogens.

MEASURING PLANT STRUCTURE AND FUNCTION USING OPTICAL REMOTE SENSING – CURRENT STATUS AND RECENT ADVANTAGES OF AIRBORNE AND SATELLITE REMOTE SENSING AND THEIR POTENTIAL FOR DISEASE DETECTION

RASCHER U. (1)

(1) Forschungszentrum Jülich, Jülich, GERMANY

We have experienced a great increase of earth observation satellites in the past years and nowadays a large number of satellite earth observation products are available on user-friendly platforms. Despite this large number of remote sensing products, it remains a challenge to detect plant diseases early from satellite data. The main challenges are related to the small symptoms that often are hidden in the large satellite imagery and insufficient revisiting time of many satellite platforms.

In this didactical presentation an introduction based on optical remote sensing is given and recent advances in Earth Observation will be highlighted. Existing multi-spectral mission recently launched hyper-spectral mission concepts, as well as fluorescence and thermal approaches will be reviewed on their potential for disease detection.

HARNESSING REMOTE SENSING AND IMAGING SPECTROSCOPY FOR SCALABLE SOLUTIONS IN AGRICULTURAL DISEASE MANAGEMENT : A NOVEL FRAMEWORK FOR RISK PREDICTION

GOLD K. (1)

(1) Plant Pathology and Plant-Microbe Biology Section, School of Integrative Plant Sciences, Cornell AgriTech, Cornell University, Geneva Ny, UNITED STATES

The growing challenges in agricultural production, including climate change and increasing food demand, necessitate innovative and scalable solutions for detecting and managing pests and diseases. Remote sensing, specifically imaging spectroscopy (IS), offers a unique opportunity to improve food security by providing a scalable detection method for biotic stress in plants. However, the underlying biological mechanisms and evolutionary conservation of these processes remain poorly understood, limiting the widespread adoption of IS in agricultural disease surveillance. This keynote presentation will address the potential of remote sensing, specifically imaging spectroscopy, as a scalable detection method to enhance food security, improve agricultural viability, and parameterize epidemiological models. Dr. Gold's Grape Sensing, Pathology, and Extension Lab (GrapeSPEC) at Cornell AgriTech studies the fundamental and applied science of plant disease sensing using high spectral- and spatial-resolution spectroscopic imagery from a variety of platforms, including autonomous ground robots and high-resolution satellites, to create disease surveillance and management intervention decision support systems. Gold will introduce how her lab uses the disease triangle as a theoretical framework to map and predict biotic stress risk with imaging spectroscopy across scales, enabling them to transform remote sensing data into actionable risk assessments. This novel approach can provide crucial insights for managing outbreaks and understanding environment-host-pathogen interactions at scale. By incorporating sensitive plant traits from high-resolution hyperspectral and thermal remote sensing imagery, representation of the virulent pathogen component of the disease triangle can be significantly improved, enhancing the accuracy and utility of these risk assessments. The integration of remote sensing, robotics, and theoretical frameworks like the disease triangle can transform agricultural disease detection and management, ultimately enhancing food security and sustainability in the face of global challenges.

ESTIMATING BEET YELLOWS SEVERITY AT PLOT RESOLUTION WITH SATELLITE OBSERVATIONS

SOUBEYRAND S. (1), JOUDELAT F. (2), RYNKIEWICZ J. (3), GABRIEL E. (1)

(1) INRAE, Avignon, FRANCE; (2) ITB, Paris, FRANCE; (3) Université Paris 1 Panthéon-Sorbonne, Paris, FRANCE

Beet yellows is now perceived as a major problem in plant health in Europe due to the modification of the regulations concerning the use of phytosanitary products. An agro-ecological approach to this issue requires actions at multiple levels, via prophylaxis, treatments and insurance systems in particular. To implement these actions effectively, we need an increased level of information. With this in mind, we are interested in a way to estimate the severity of beet yellows at plot resolution over large territories. We have thus developed an approach combining field observations (precise but partial) and satellite observations (less precise but with a high coverage rate). We tested different supervised approaches exploiting raw images or indices calculated on the basis of images, as well as a post hoc approach allowing to integrate multi-scale dependencies between observations.

HIGH-RESOLUTION HYPERSPECTRAL AND THERMAL IMAGING FOR THE EARLY DETECTION OF PLANT DISEASES. PROSPECTS AND LIMITATIONS.

ZARCO-TEJADA P. (1), POBLETE T. (1), CAMINO C. (2), CALDERON R. (3), HORNERO A. (4), HERNANDEZ-CLEMENTE R. (5), GONZALEZ-DUGO V. (4), LANDA B. (4), NAVAS-CORTES J. (4)

(1) University of Melbourne, Melbourne, AUSTRALIA; (2) EC-JRC, Ispra, VA, ITALY; (3) University of Cornell, Ithaca, UNITED STATES; (4) IAS-CSIC, Cordoba, SPAIN; (5) Universidad de Cordoba, Cordoba, SPAIN

Progress in the last 20 years in thermal and imaging spectroscopy has advanced tremendously, allowing the large-scale monitoring of crop physiological processes. Successes have been obtained in biotic and abiotic stress detection, particularly through sensor miniaturization and innovative physically- and artificial intelligence-driven modelling techniques. These developments have enabled the screening of subtle physiological changes through spectral analysis. Remote sensing efforts as part of European initiatives (POnTE, XF-ACTORS and recently BeXyl), and through regional programs have focused on the development of algorithms for the early detection of *Xylella fastidiosa* and *Verticillium dahliae* -induced symptoms. These studies have shown that using specific spectral plant traits successfully reveals infections at early / pre-visual stages. Nevertheless, several issues remain to be addressed, such as i) lack of high spatial resolution hyperspectral satellite images to detect subtle physiological changes on individual tree crowns; ii) lack of high-resolution thermal imagery to detect changes linked to transpiration reduction in infected vegetation; iii) lack of suitable multispectral bandsets in commercial satellite sensors; and iv) limited scale coverage of airborne hyperspectral and thermal sensors (i.e. drones and piloted platforms). These aspects will be discussed in the context of global detection and monitoring of harmful organisms causing plant diseases.

COMBINING REMOTE SENSING AND EPIDEMIOLOGICAL MODELLING TO IMPROVE MANAGEMENT OF RED NEEDLE CAST OF RADIATA PINE IN NEW ZEALAND

FRASER S. (1), MCLAY E. (1), CAMARRETTA N. (1), PEARSE G. (1)

(1) Scion, Rotorua, NEW ZEALAND

Red needle cast (RNC), primarily caused by *Phytophthora pluvialis*, is one of the most important diseases of *Pinus radiata* (radiata pine) in New Zealand. The disease causes reddening and premature cast of needles, leading to growth loss. The disease predominantly affects the lower crown but extends to the whole of the crown in severe cases. Disease expression generally begins in autumn, with disease severity developing rapidly and peaking in winter or spring. Remote Sensing approaches are being used to investigate several aspects of RNC, including epidemiology, growth impacts, and control options, with an aim to support the development of management options. High resolution imagery from fixed cameras, UAV, fixed-wing aircraft, and satellites is used to manually score trials in mature forests. A combination of terrestrial and aerial LiDAR has been used to map mature trees to allow aerial assessments of individual trees to be combined with on-ground weather, disease, and growth data. Frameworks have also been developed for the use of high- and low- resolution satellite imagery to automatically map and monitor outbreaks of RNC. Simultaneously, data on the environmental tolerances of the different pathogen life stages are being used to develop a process-based infection risk model, for which a range of remote sensing data will be used for calibration and validation. The benefits of this multi-disciplinary approach and the specific challenges of this system will be discussed.

CAN REMOTE SENSING DATA IMPROVE MATHEMATICAL MODELS FOR TACTICAL DECISION MAKING AND FUNGICIDE APPLICATION?

FEDELE G. (1), SALOTTI I. (1), CAFFI T. (1), **ROSSI V. (1)**

(1) Università Cattolica del Sacro Cuore - Department of Sustainable Crop Production (DI.PRO.VE.S.), Piacenza, ITALY

Remote sensing has supported applications on crop fertilization and irrigation, weed management and yield estimates. Applications for disease control, however, are still at small-scale, pilot development. How to use remote sensing data in decision making for tactical crop protection needs further investigation. These tactical decisions include (i) whether and when a fungicide application is needed, (ii) which fungicide(s) should be used, and (iii) at what dosage, which are supported by disease and fungicide models. Disease models provide information on infection events and their severity, and on the length of incubation and latent periods, so they guide fungicide timing and the activity the fungicide may have (pre- or post-infection, pre- or post-symptoms). Fungicide models define the degree and the duration of the fungicide activity; these models can be complemented by plant growth models that help estimating the fungicide dilution after application. Remote sensing data have the potential to supplement disease, plant and fungicide models in order to improve models' outputs and, finally, decision making. For instance, early detection of infection can be used to validate disease model predictions and support pre-symptom application of fungicides. Assessment of plant growth and development through vegetational indexes can improve the accuracy of fungicide models and support better (and spatially variable) definition of the fungicide dosage. Examples are provided for vineyards.

MAPPING GLOBAL RISK OF FUSARIUM WILT IN A CHANGING CLIMATE WITH REMOTE SENSING AND AEROSOL TRANSPORT MODELING

CALDERON R. (1), BRODSKY H. (2), VOSBURG C. (3), ELLER J. (1), MILES A. (3), MAHOWALD N. (2), CRANDALL S. (3), PAVLICK R. (4), GOLD K. (1)

(1) Plant Pathology and Plant-Microbe Biology Section, School of Integrative Plant Sciences, Cornell AgriTech, Cornell University, Geneva Ny, UNITED STATES; (2) Department of Earth and Atmospheric Sciences, Atkinson Center for a Sustainable Future, Cornell University, Ithaca Ny, UNITED STATES; (3) Department of Plant Pathology and Environmental Microbiology, Pennsylvania State University, University Park Pa, UNITED STATES; (4) Jet Propulsion Laboratory, California Institute of Technology, Pasadena Ca, UNITED STATES

Fusarium oxysporum (*Fo*) is a ubiquitous soilborne fungus that can cause Fusarium wilt (FW) in 100+ crops. Uncertainties in aspects of its epidemiology and a lack of global distribution data have historically challenged monitoring and containment efforts. Our NASA Interdisciplinary Sciences project seeks to address this need by integrating remote sensing, aerosol transport modeling, and comparative genomics to build a global disease surveillance system for FW incidence and *Fo* dispersal risk in aerosolized agricultural dust. As foundation, we released an interactive, global web map documenting 4500+ FW incidences reported in peer-reviewed literature. Here, we developed a global susceptibility assessment that integrates all three aspects of the disease triangle. We identified agricultural production zones conducive to FW, noting subsets capable of serving as dust sources, by overlapping the MODIS Deep Blue algorithm with a Landsat-based cropland product. We then restricted this assessment to only regions with reported *Fo* in the past 30 years. Conducive disease environment was modeled using multiple satellite-derived products with species distribution modeling. Results from this assessment along with aerosol transport modeling can inform how related incidence sites on opposite ends of dust events may be. This integrated approach to disease surveillance can provide key insights about drivers for current and future FW distribution and the spread of *Fo* on global dust currents.

AN EPIDEMIOLOGICAL MODEL TO ASSESS THE EFFICACY OF MONITORING TECHNOLOGIES FOR EARLY DETECTION OF TREE PESTS AND PATHOGENS AT LOCAL AND TREESCAPE LEVELS

MCMENEMY P. (1), KLECZKOWSKI A. (1), GAULTON R. (2), POCOCK M. (4), BROWN P. (3)

(1) University of Strathclyde, Glasgow, UNITED KINGDOM; (2) University of Newcastle, Newcastle, UNITED KINGDOM; (3) FERA, York, UNITED KINGDOM; (4) UK Centre for Ecology and Hydrology, Bangor, UNITED KINGDOM

Trees are an essential natural resource that stores carbon, provides habitats and food for wildlife and is an important ecosystem service. Nevertheless, they are under increasing threat from pests and pathogens. Efficient monitoring of tree conditions is needed to respond efficiently to plant health threats and minimise the risk of new outbreaks. Monitoring of tree health through visual inspection alone is prone to error and bias and consumes time, monetary and human resources. Thus, it would be in the interest of stakeholders if tree health could be assessed and monitored rapidly while utilising sensors and technologies, from Internet of Things (IoT) devices through drones and satellite imagery which in addition offer continuous monitoring. However, each of the technologies comes with limitations and costs. We assess their monitoring potential with a spatially-extended metapopulation model of a landscape consisting of woodland parcels, incorporating both local and long-distance spread. We include the IoT/visual inspections, which are potentially able to detect low levels of stress but at a high cost and low frequency. We contrast this approach with satellite imagery which offers continuous monitoring over large areas, but with a significantly lower resolution. The detection process is quantified by the time from the start of the epidemic to the first detection. We then relate the efficacy to the total cost of the monitoring programme.

COMBINING DATA AND KNOWLEDGE FOR DISEASE SPREAD MODELING AND SIMULATION SHOWN FOR CERCOSPORA LEAF SPOT IN SUGAR BEET

GÜNDER M. (1), ISPIZUA YAMATI F. (2), MAHLEIN A. (2), BAUCKHAGE C. (1)

(1) University of Bonn, Bonn, GERMANY; (2) Institute for Sugar Beet Research, Göttingen, GERMANY

For an efficient and sustainable management of plant diseases, knowledge about their temporal and spatial occurrence and development is crucial.

To enable targeted and site-specific management measures such as site-specific application, the development of models for large-scale fields is necessary. Traditional models are based on environmental parameters and knowledge on the pathogen's epidemiology, integrating management practices. More recent technologies and innovations from the field of optical sensors and artificial intelligence provide the potential to improve data- and knowledge-based models.

In this work, we present a use case of a simulation model for Cercospora Leaf Spot (CLS) in sugar beet, caused by the fungal agent *Cercospora beticola*. Therefore, we combine data from optical sensors mounted on drones, weather, and environmental data with epidemiological knowledge to establish a simulation model for the occurrence and development of CLS. Furthermore, we integrate and simulate different fungicide applications and spread scenarios. As an outcome of our study, we are able to model the disease spread by Spatio-temporal Point Processes (STPPs). This approach will support the generation of risk maps and to establish specific fungicide application maps for CLS and other diseases on the field level.

INTEGRATING UAS-BASED MULTISPECTRAL IMAGING AND EPIDEMIOLOGICAL MODELING IN CEREAL CROPS

GONGORA-CAUL C. (1), ZHANG C. (1), OH S. (1), **CRUZ C. (1)**

(1) Purdue University, West Lafayette, UNITED STATES

Detecting and estimating disease intensity at the plant population level primarily rely on visual sign and symptom assessments. This traditional approach can be reliable if done correctly but labor-intensive, low-throughput, and prone to human subjectivity. Evidence suggests that sensor-based technologies offer a new opportunity to quantify disease intensity. Our group seeks to combine imagery and epidemiological modeling using wheat blast and corn tar spot as model systems. Through manuscripts published in 2020 and 2021, we demonstrated that the intensity of wheat blast or corn tar spot could be quantified using UAS-based multispectral imagery with varying levels of accuracy ($0.69<\rho_c<0.92$). In 2023, we demonstrated that image-based features and machine learning could be used to estimate tar spot epidemiological parameters from UAS-based multispectral images collected in field efficacy trials. Disease severity was assessed visually at three canopy levels within micro-plots for two years, while aerial images were gathered with UASs equipped with multispectral cameras. The developed models estimated disease severity at distinct canopy levels ($r\geq0.93$; $\rho_c\geq0.97$), and data were used to model disease progression. Parameters y_0 and AUDPC derived from visual and estimated disease severity were similar, but significant differences ($\alpha=0.05$) between K_{max} or r_L were found. Further studies are required to improve or transfer methods.

COMBINING IMAGING AND SPATIALLY-EXPLICIT MODELLING FOR THE STUDY OF PLANT DISEASES : LESSONS LEARNED FROM THE STUDY OF PLANT PATHOGEN LESIONS

LECLERC M. (1)

(1) INRAE, Le Rheu, FRANCE

The use of mathematical models offers a means to analyse epidemiological data. Despite the recent development of imaging technologies to monitor plant diseases at various scales, these new data are still seldom used to fit mechanistic models and estimate key parameters.

In this presentation we present how combining image-based phenotyping with reaction-diffusion models provides new insights into the spread of plant pathogen lesions. The proposed approach consists in i) monitoring inoculated leaflets through imaging, ii) using computer vision methods to align images to each other and segment symptomatic tissues, and iii) fitting a reaction-diffusion model to image sequences with a variational data assimilation approach. This modelling framework was used to analyse data obtained on several pathosystems for a range of pathogen isolates and plant cultivars. It enables one to disentangle the processes involved in host-pathogen interactions and gives new quantitative traits for assessing host resistance and/or pathogen aggressiveness.

Similar approaches may be implemented by plant disease epidemiologists to understand the spread of pathogens at larger spatial scales using remote sensing data. Besides the methods used for processing images produced by remote sensing, modellers will have to integrate image-data assimilation methods and perhaps, take into account the errors produced by computer vision algorithms to better estimate the parameters of mechanistic models.

UNDERSTANDING FALL ARMYWORM INFESTATION IN MAIZE FIELDS OF BANGLADESH USING TEMPORAL SENTINEL-2 DATA

DZURUME T. (1), DARVISHZADEH R. (1), KRUPNIK J. (2), BABU T. (2), RAHMAN A. (2), BILLAH M. (2), SYED N. (2), KAMAL M. (2), NELSON A. (1)

(1) Department of Natural Resources, Faculty of Geo-Information Science and Earth Observation, University of Twente, NETHERLANDS; (2) CIMMYT-Bangladesh, Dhaka, BANGLADESH

Fall armyworm (FAW), J.E. Smith *Spodoptera frugiperda*, is one of the most harmful crop pests that has caused a significant threat to food security worldwide. In Bangladesh, FAW was first detected in November 2018 and since then has affected the production of maize in the country. The study aimed to map the intensity of FAW infestation in maize fields across Bangladesh using Sentinel-2 data and machine learning algorithms. Field data was collected in six divisions of Bangladesh by CIMMYT -Bangladesh during the 2019 (December)–2020 (March) maize growing season. In total, 579 maize fields were sampled, and 6998 maize field samples were taken by means of weekly scouting across the divisions. Sentinel-2 spectral indices and bands were investigated to identify spectral features altered by the infestations. The Partial least squares discriminant model was trained using field-collected samples, and its accuracy was assessed. Our preliminary results show that FAW infestation intensity can be mapped using temporal Sentinel-2 data. Identifying FAW infestation intensity and hot spots using remote sensing is an effective and valuable approach for early estimation of damaged maize and yield and to plan crop management mitigations.

A MODELLING APPROACH TO MAP THE RISK OF HLB IN THE IBERIAN PENINSULA

ELLIS J. (1), LAZARO HERVAS E. (3), VICENT CIVERA A. (3), PARNELL S. (2), CUNNIFFE N. (1)

(1) University of Cambridge, Cambridge, UNITED KINGDOM; (2) University of Warwick, Warwick, UNITED KINGDOM; (3) Instituto Valenciano de Investigaciones Agrarias, Valencia, SPAIN

Huanglongbing (HLB), or citrus greening, is a devastating citrus disease, currently found in Asia, Africa and North and South America. At present, no cases of HLB have been found in Europe, but in the past decade one of the disease vectors, the African citrus Psyllid (AfCP), has been found in several locations in North-Western Spain and Portugal. The presence of an established vector population means there is a high risk of transmission between citrus if HLB is subsequently introduced.

We present the findings of a 1 km^2 computational model of vector and pathogen spread in the Iberian Peninsula. The density of citrus in residential areas and commercial orchards, as well as climate suitability, both influence the pattern of spread. The majority of vectors disperse locally and are dependent on the availability of citrus plants, but we also account for long-distance dispersal via mechanisms such as wind or human transportation. Using the current estimated distribution of AfCP as an initial condition, results often show a pattern of slow growth of the psyllid in the North-West. However, once long-distance dispersal or new introduction of psyllid into the densely populated commercial citrus regions in the South or East of Spain occurs, the population quickly increases. There is subsequently a high risk of rapid spread of HLB upon the introduction of an infected plant in this region.

DISEASE CLIMATIC RISK MODEL INTERPRETATIONS AT MULTIPLE SPATIAL SCALES

CAMPBELL R. (1), BERESFORD R. (2)

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Climatic risk models are often used to help understand the areas and seasons where invading organisms will have the greatest risk of establishing and causing a negative impact. These risk models often make predictions for a large spatial scale using inputs of time-averaged climatic data (e.g. annual). However, many organisms respond to, or have mechanisms influenced by, much shorter time scales (e.g., diurnal effects) and finer spatial scales (e.g., microclimate effects). Large-scale averaging may hide important information and could lead to misrepresentation of the dynamics of pathogen and pest populations and their spread in time and space. This risks misinterpretation of risk and errors in surveillance and management efforts. We use the existing myrtle rust (*Austropuccinia psidii*) climatic risk model in conjunction with field data, as an example to explore the scale of variability in microclimate variables across forest edges and what that could mean for risk model interpretations. These are compared to risk predictions from the national forecast grid, regional weather stations and local weather stations. We discuss the implications of these comparisons to risk predictions for future incursion responses, for example *Xylella fastidiosa*, and what resolution is ‘good enough’ for what particular purpose.

THE UTILITY OF PROXIMAL SENSING AND DEEP LEARNING IN THE DETECTION AND CHARACTERIZATION OF TAR SPOT EPIDEMICS ON CORN IN THE UNITED STATES

LEE D. (1), NA D. (1), GÓNGORA-CANUL C. (2), GOODWIN S. (3), LEE J. (1), CRUZ C. (4)

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In recent years, the widespread incorporation of image sensors through proximal or aerial remote sensing has proven their utility as an alternative approach to conventional, human-vision-based disease estimation. Nevertheless, from a disease management standpoint, obtaining objective, accurate, and high-throughput measurements of signs and symptoms during the growing season are critical in sensor-based phenotyping. Since its first identification in 2015 in the United States., tar spot of corn caused by *Phyllachora maydis* has rapidly spread from Illinois and Indiana through the corn belt and south to Florida. The detrimental impact on yield and the polycyclic nature of tar spot epidemics have made this disease one of the most significant emerging diseases of corn in the United States. In my talk, I will share our work towards developing a pipeline consisting of the previously developed Stromata Contour Detection Algorithm (SCDA v1) and the generation of a Convolutional Neural Network (CNN). Our approach allows high-throughput and automated detection and quantification of tar spot stromata in Red-Green-Blue (RGB) images of corn leaves collected at multiple experimental sites in Indiana in 2021 (onset to later stages of tar spot development). Our work will serve as a foundation for building an accurate and reliable standardized approach that can be utilized nationally and internationally for tar spot research, disease management, surveillance, and epidemiological modeling.

INTEGRATING REINFORCEMENT LEARNING AND EPIDEMIOLOGICAL MODELS FOR DISEASE CONTROL OPTIMISATION WITH LIMITED INFORMATION

TRIMBLE R. (1), CUNNIFFE N. (1)

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Epidemiological modelling is well established as a method to evaluate options for control of epidemics across human, animal and plant health. Those advising stakeholders may simulate the model to trial management strategies or use analytical techniques to optimise control. However, trial and error analysis risks selecting suboptimal strategies and analytical models require significant approximations to be tractable for realistic systems. Reinforcement learning is an approach to optimise sequential decision making which has been used in fields as wide ranging as chess, robotics and control of fusion reactors. The target problem is framed as interactions between an agent and an environment (in this case, a simulated epidemic) and the algorithm learns to optimise the outcome (e.g. the number of plants lost to disease) by targeted exploration of the state space. A key challenge for any control optimisation is acting in situations with partial observability — where parts of the system can be observed but the underlying state of the system is not known. This work applies reinforcement learning to a model of landscape level plant disease spread and breaks down how different elements of model observability and environment formulation make the learning more or less effective. In the context of remote sensing, this work may provide insights into how improving different types of observability in landscape scale epidemic control can improve our ability to optimise epidemic outcomes.

QUANTIFYING VCMAX AND PLANT TRAITS TO MONITOR FOREST DECLINE SYMPTOMS BY COUPLING SATELLITE IMAGES AND BIOPHYSICAL MODELS

CAMINO C. (1), ARAÑO K. (1), DUTRIEUX L. (1), ARRIGA N. (1), GOMARASCA U. (2), ŠIGUT L. (3), PAVELKA M. (3), KOWALSKA N. (3), LUKEŠ P. (3), CAUDULLO G. (1), ZARCO-TEJADA P. (4,5), MIGLIAVACCA M. (1), BECK P. (1)

(1) Joint Research Centre, Ispra, ITALY; (2) Max Planck Institute, Jena, GERMANY; (3) Global Change Research Institute of the Czech Academy of Sciences, Brno, CZECH REPUBLIC; (4) School of Agriculture and Food & Faculty of Engineering and Information Technology (FEIT), University of Melbourne, Melbourne, AUSTRALIA; (5) Instituto de Agricultura Sostenible, CSIC (Consejo Superior de Investigaciones Científicas), Córdoba, SPAIN

As climate change and globalization are changing forest pathogens and pests distributions and dynamics, accurate forest health monitoring (FHM) systems are increasingly sought after by forest managers to detect and prevent forest disturbances. We developed a hybrid machine learning approach that couples the SCOPE radiative transfer model with Sentinel-2 (S2) satellite time series to estimate maximum carboxylation rate (Vcmax) and leaf biochemical constituents. We found that our predictions matched with the estimates of gross primary productivity better in deciduous broadleaf forests than in forests dominated by needle-leaved evergreen trees. To verify the effectiveness of the proposed FHM system, we explored its capacity to estimate key plant physiological traits and red-edge spectral indicators in the Pinus pinea L. (Stone pine) forest stand monitored through the San Rossore 2 ICOS Ecosystem station in Italy, where an outbreak of a parasitic fungal infection occurred in the summer of 2020. The results reveal that the Vcmax, pigments, leaf water content and the red-edge indicator S2 showed to be more effective than conventional indices (e.g., NDVI) for the early detection of this fungal infection. Our work demonstrates the potential of coupling radiative transfer models and S-2 images to monitor plant physiological traits in support of FHM activities, particularly in the context of pest epidemics

REMOTE SENSING IN SUPPORT OF PLANT DISEASE DETECTION AT DIFFERENT SPATIAL SCALES

DELALIEUX S. (1), TITS L. (1)

(1) VITO, Mol, BELGIUM

For an efficient Integrated Pest Management (IPM), the ability to monitor the plant's health status to early spot diseases has proven essential. Among the methods to monitor plant diseases, remote sensing (RS) stands out as an excellent tool. However, along with a wide diversity of plant monitoring needs, there is also a wide variety of RS-based plant disease monitoring tools, each tailored to specific needs within the IPM. Within-field monitoring tools, such as sensors mounted on tractors, are critical in many production systems for which disease symptoms cannot be properly detected from a top-view perspective. This has been demonstrated in pear orchards for fire blight detection. Drones on the other hand, provide detailed information at the field level, enabling the monitoring of individual leaves and plants. This has proven to be useful in the detection of, e.g., Powdery Mildew in sugar beets, or Banana Wilt Disease. The downside of this technology is however the revisit time as well as the scalability to the regional level. To this end, satellites have demonstrated their potential in providing frequent and large-scale information on the phenological stages of crops as well as on their general health condition, both essential for a proper disease spread modelling. Based on VITO's long-standing research in the use of RS technology for disease detection and monitoring, an overview of these technologies will be presented, together with their merits and pitfalls.

LIST OF ALL POSTER PRESENTATIONS

Abstracts for the poster presentations tabulated below are given in the subsequent pages.

HIGH RESOLUTION MULTISPECTRAL UAV IMAGERY FOR DISEASE QUANTIFICATION: AN ALTERNATIVE FOR LEAF DISEASE MANAGEMENT IN SUGAR BEET

BARRETO ALCANTARA A. (1), ISPIZUA YAMATI F. (1), MAHLEIN A. (1)

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In sugar beet production, managing leaf diseases is one of the most relevant activities to safeguard yield. To initiate a control measure, exhausting visual scoring activities must be conducted to release a warning signal based on disease quantification parameters such as disease incidence (DI). By the end of the growing season, a georeferenced estimation of disease severity (DS) can deliver spatial information on yield and pathogen distribution; this last aspect is crucial to track epidemics in the following years. Unmanned aerial vehicle (UAV), multispectral imagery, and deep instance segmentation networks enable an in-field detection and quantification of plant disease. The extraction parameters improve the knowledge of temporal and spatial development of disease. For determining DI and DS, the concept of scoring unit was transferred from practical use to an image-based perspective to analyze recorded fields at leaf and plot level. The results give an overview of how the accuracy of deep learning models and image-based “decision-making” criteria affects the performance of DI. Moreover, a better understanding of the disease spread is available by analyzing various metrics of DS, such as number of clusters, cluster area, and ratio of damaged leaf regions. The results of this work will deliver a possible solution to reduce the so far very laborious work of visual disease assessments in the field and thereby automate warning systems for disease management itself.

ASSESSING LONG-DISTANCE, TRANSOCEANIC AND INTERCONTINENTAL ATMOSPHERIC TRANSPORT OF SOILBORNE PLANT PATHOGENS ENTRAINED WITH AEROSOLIZED AGRICULTURAL DUST

BRODSKY H. (1), **CALDERON R. (2)**, HAMILTON D. (3), LONGLEI L. (1), MILES A. (4), PAVLICK R. (5), GOLD K. (2), CRANDALL S. (4), MAHOWALD N. (1)

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Soilborne pathogenic fungi are a leading cause of crop disease and are primarily spread through microscopic, durable spores adapted differentially for both persistence and dispersal via soil, animals, water and atmosphere. While intracontinental aerial dispersion of soilborne fungal spores has been well established, transoceanic and intercontinental atmospheric transport of these spores entrained with aerosolized agricultural dust is understudied and may contribute to disease spread. Our NASA ROSES project seeks to address this need by integrating remote sensing, aerosol transport and comparative genomics to assess the long-distance atmospheric dispersal of the plant pathogenic, soilborne fungus *Fusarium oxysporum* (*Fo*) on global dust currents. The CAM6-MIMI climate model was modified to incorporate spore traits that influence dispersal and atmospheric survival, and was parameterized using the 2020 Godzilla dust event. We found modeling evidence of transoceanic and intercontinental atmospheric transport of viable *Fo* spores and offered a danger index for *Fo* spore deposition on susceptible agricultural zones. The main long-distance transport of viable spores and the highest danger for deposition on cropland are between the regions of Eurasia, North Africa, and Sub-Saharan Africa. This study provides key insights about Fusarium wilt epidemiology and lays the groundwork to build an operational, real-time global surveillance system of long-distance plant pathogen transport risk.

DISEASE SPREAD DYNAMICS FROM MONITORING AT DIFFERENT SPATIAL AND TEMPORAL SCALES

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Apple canker (AC) is a fungal disease caused by *Neonectria ditissima* that is primarily rainsplash dispersed and has a variable latent period from weeks to years. These features help to promote a non-random spatial pattern of disease incidence within and across orchard blocks, with hot-spots that can persist in the same location over several years. Spatial disease incidence dynamics were analysed from empirical data varying in temporal and spatial resolution. Temporal comparisons were made between yearly and monthly tree level disease incidence records. Incidence over time was also related to environmental factors, seasonal availability of wounds and expected latent periods. One set of incidence data was recorded at a precise spatial scale by recording the location of individual trees, whereas the other data set approximated location to the orchard 'bay' (± 10 m within a tree row). Disease spread patterns were also analysed both within-block (single cultivar and uniform management) and across-blocks (multiple apple cultivars; differing plant spacing and age). Spatial models were developed using empirical and mechanistic approaches incorporating the spatial and temporal differences in data resolution. Implications of spatial modelling with different resolutions of spatial and temporal scales are discussed for application to efficiently manage and predict the spread of AC in New Zealand apple orchards.

PREDICTING STRESS CAUSED BY GRAPEVINE POWDERY MILDEW WITH NASA AIRBORNE IMAGING SPECTROSCOPY IN NAPA VALLEY, CALIFORNIA

ELLER J. (1), ORME A. (2), ROMERO GALVAN F. (1), PALVICK R. (4), WHITCRAFT A. (3), GOLD K. (1)

(1) Cornell University, Geneva, Ny, UNITED STATES; (2) California State University, Northridge, Northridge, Ca, UNITED STATES; (3) University of Maryland, College Park, Md, UNITED STATES; (4) Jet Propulsion Laboratory, Pasadena, Ca, UNITED STATES

Powdery mildews cause $42.8B in damage annually and are notoriously ubiquitous with 10,000+ host species on all crop producing continents. Grapevine (*Vitis vinifera*) Powdery Mildew (GPM; *Erysiphe necator*) is responsible for >90% of negative environmental consequences associated with vineyard management globally as effective control necessitates high frequency fungicide application. While mechanistic models to predict GPM incidence and spread exist, their accuracy is limited by uncertainty in underlying initial disease distribution. The overall goal of this work is to develop a quantitative index for GPM rooted in disease physiology that can be used to parameterize epidemiological models with NASA Airborne Visible and Infrared Imaging Spectrometer Next Generation (AVIRIS-NG) hyperspectral imagery collected over Napa Valley, CA. We compared Normalized Difference Vegetation Index (NDVI), Red-Edge NDVI (NDVIre), Plant Senescence Reflectance Index (PSRI), and others as viable early indicators of GPM-induced stress and compared their accuracy when derived from hyperspectral and multispectral (Sentinel-2) sources. We found NDVIre derived from AVIRIS-NG to be the most accurate indicator of grapevine health and vigor as relates to potential GPM-stress, especially once vines have amassed significant foliar chlorophyll. The next step for this work is to compare the distribution yielded by our quantitative index to simulations from the Gubler-Thomas.

A COMPARTMENTAL MATHEMATICAL MODEL BASED ON APHID FEEDING BEHAVIOURS ALLOWS MORE REALISTIC MODELLING OF NON-PERSISTENTLY TRANSMITTED PLANT VIRUSES

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Plant viruses threaten global food security and are often transmitted by arthropod vectors. Non-persistently transmitted (NPT) plant viruses are characterised by a very short virus retention time in the vector and are transmitted almost exclusively by aphids. Compartmental models using ordinary differential equations to capture the course of an epidemic have been used in plant virus epidemiology for decades. However, the underlying model structure, in which the infective period of vectors is fixed, omits a key feature of non-persistent transmission: probing or feeding on a plant is often what causes an aphid to lose its infectivity. A recent model by Donnelly et al. (2019) captures this behaviour via a Markov chain that tracks the behaviour of individual aphids. We introduce a new compartmental model which replicates this model, while allowing the easy extensibility characteristic of compartmental models. It is comprised of linked Susceptible-Infected models for the plants and aphids, where loss of aphid infectivity is conditioned upon its probing and feeding behaviour, rather than occurring at a fixed rate. This additional biological realism means our model behaves differently to previous compartmental models of NPT viruses, therefore allowing us to more accurately investigate virus transmission dynamics for all NPT systems. We focus on the case of viral manipulation of host plant phenotype, which changes aphid landing and feeding behaviour to enhance virus spread.

VOLATILE ORGANIC COMPOUNDS -CHEMICAL SIGNALS TO COMMUNICATE PLANT HEALTH

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Plants and their respective pests, including pathogens, communicate their physio-chemical status to their surroundings by emitting volatile organic compounds (VOCs). The specificity and uniqueness of these VOCs could be utilized as “infochemicals” to detect, identify and monitor diseases. Pre-symptomatic detection would allow more targeted and less resource intensive pest control strategies to be employed. In addition, the release of pathogen-related VOCs might elicit defense responses in neighboring plants that delay the spread of the disease within the crop stand. As such, the study of VOCs holds an untapped potential in plant pathogen epidemiology and management. We have collected VOCs emitted from wheat grown both in the greenhouse and in the field exposed to different fungal pathogens and identified those compounds emitted from infected plants by GC-MS. Concentrations of VOCs were very low, but the target diseases could be identified based on the VOC profiles of the infected host plants. The project ‘PurPest- Plant Pest Prevention through technology-guided monitoring and site-specific control', currently funded by EU’s Horizon Europe program, is exploring the most recent sensor technology to detect and identify pathogens and insect pests based on their VOC signature in host plants to limit their spread, target control measures and better understand the drivers of pest invasion.

PAIRING HIGH RESOLUTION SATELLITE IMAGERY AND TERRESTRIAL ROBOTICS TO DETECT AND MONITOR GRAPEVINE DOWNY MILDEW EPIDEMICS

KANALEY K. (1), PAUL A. (1), COMBS D. (1), LIU E. (2), JIANG Y. (2), GOLD K. (1)

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Grapevine downy mildew (GDM), caused by the oomycete *Plasmopara viticola*, plagues humid production regions and can cause 100% yield loss and vine death under conducive conditions. Growers currently rely on frequent fungicide applications for control, but this practice has led to widespread resistance. Rapid remote detection and mapping of GDM outbreaks would enable precision pesticide applications to target high performing but resistance-prone fungicides where and when most needed, while relying on less resistance-prone protectants elsewhere. To actualize this vision, we investigated two platforms for GDM surveillance: high resolution, multispectral satellite imagery and a terrestrial robotic imaging system at the Cornell Pathology Vineyard in Geneva, New York. We evaluated several supervised and unsupervised methods to predict disease severity using satellite spectral features as input. Spectra and vegetation health indices derived from Planet Labs SkySat imagery (50cm pixel size) could differentiate between healthy and diseased vines even at low GDM severity (10% symptomatic leaf area). Automated severity ratings derived from rover-based imagery also correlated well with human scout ratings ($r > 0.75$). Our next step is to integrate the two systems by training satellite imagery on rover generated severity maps. Our results thus far indicate that both satellite and terrestrial robotic platforms are promising methods for mapping GDM incidence and severity.

USING CROP CLASSIFICATION FROM SATELLITE TO ESTIMATE THE RISK OF BLACKSPOT IN FIELD PEAS ON THE SOUTH AUSTRALIA EYRE PENINSULA

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In Australia, field pea sowing date is dependent on blackspot infection risk from showers of Didymella pinodes ascospores produced on crop stubble from preceding seasons. Ascospores are wind dispersed during discrete rainfall events that trigger ascospore release. Yield losses of up to 60% can occur when blackspot risk is highest early in the season when ascospores are abundant on the preceding seasons' field pea stubble. The risk of severe blackspot epidemics can be significantly reduced when the residual ascospore load is depleted to 40% or less. The Blackspot Manager model predicts ascospore dispersal events from rainfall and temperature observations and then estimates the date when this threshold has likely been met. However, the current generation of Blackspot Manager does not employ crucial spatial information contributing to disease risk, such as the proximity to previous seasons' field pea crop residue. Remotely sensed satellite data can be used to identify paddocks which grew field pea in previous seasons and thus are likely to be sources of inoculum. We used this data to inform a spatio-temporal blackspot spore dispersal model which estimates disease risk at the sub-paddock scale. With the incorporation of spatial data, the model can improve decision support offered by the original Blackspot Manager model by informing growers where paddocks are safe to sow earlier in the season and avoid blackspot spore showers, and where individual paddock risk is high, and sowing should be delayed.

SPREAD OF NEOPESTALOTIOPSIS SP. CONIDIA FROM STRAWBERRY UNDER CONTROLLED CONDITIONS

GAMA A. (1), BAGGIO J. (1), ALONZO G. (1), **PERES N. (1)**

(1) University of Florida, Wimauma, UNITED STATES

The Florida strawberry industry has been recently affected by a new species of *Neopestalotiopsis* that is more aggressive and has caused significant losses. Since the fungus had been considered of secondary importance, little is known about its life cycle. Thus, experiments were set up in a wind tunnel to evaluate the dispersal of the pathogen from symptomatic strawberry leaves, fruit, as well as dried senescent leaves, and inoculated sandy soil. Plates with selective media for *Neopestalotiopsis* spp. were placed at 0.6, 1, 3, 5, and 7 m away from the inoculum sources, and the following treatments were tested: 5 m/s, 5 m/s + water, 7 m/s, and 7 m/s + water. To describe the dispersal gradients, an exponential model was fitted to the number of colony-forming units of *Neopestalotiopsis* sp. found on the plates and to the distance from the inoculum source. The exponential model described the dispersal gradient for treatments with water, although a few colonies were found in the treatments without water. The highest number of CFU were found in plates where strawberry fruit and strawberry dried leaves were the inoculum sources. Most inoculum moved less than 1 m, regardless of the inoculum source. The 7 m/s wind + water moved the inoculum further than 5 m/s + water. Our data suggest that *Neopestalotiopsis* dispersal occurs within short distances, but higher wind speeds, which commonly occur during storms in Florida, may move conidia longer distances.

ONE BAD APPLE: HOW DOES THE SUCCESS OF A FUNGICIDE RESISTANCE MANAGEMENT STRATEGY RESPOND TO A PROPORTION OF GROWERS WHO DO NOT FOLLOW RECOMMENDATIONS?

RICH J. (1), CUNNIFFE N. J. (1)

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A modelling approach has been taken to address the question of how spatially heterogeneous fungicide use to treat Septoria tritici blotch (STB) of winter wheat affects the rate of fungicide resistance selection in the population of the causative fungal pathogen Zymoseptoria tritici (Zt), over multiple growing seasons. Many fields of winter wheat are grown in close proximity over agricultural areas with the major source of Zt primary inoculum being widely dispersed airborne ascospores. Hence the rate of selection of fungicide resistance in the Zt population, over many years, depends on the fungicide usage of all growers over an area.

An established epidemiological model for the selection of qualitative resistance for Zt has been extended to a spatially implicit model and a separate spatially explicit model. Growers are divided into two groups based on the dose of fungicide they apply. The spatially implicit model illustrates two necessary conditions for the rate of fungicide resistance selection to be reduced through decreased fungicide usage: (i) most growers use decreased concentration fungicide programmes; (ii) there is high dispersion of primary inoculum between fields. In the spatially explicit model, ascospore dispersal is modelled explicitly using an inverse power law dispersal kernel. Spatially explicit modelling shows that condition (i) and (ii) are not sufficient for localities with a grower using a high concentration fungicide programme in a field of large area, and in such cases the rate of fungicide resistance selection is substantially increased over their locality, regardless of majority low fungicide usage and high dispersion of primary inoculum.

CLOUD-NATIVE, MACHINE LEARNING BASED DETECTION OF GRAPEVINE LEAFROLL VIRUS IN VITIS VINIFERA WITH NASA IMAGING SPECTROSCOPY IN CALIFORNIA, USA

ROMERO GALVAN F. (1), RUBAMBIZA G. (1), PAVLICK R. (2), WEATHERSPOON H. (1), GOLD K. (1)

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Early warning systems for plant disease based on remote sensing can provide rapid and accurate information for efficient resource management, thus reducing losses, expenses, and unintended negative environmental impacts. We previously found that deploying Machine Learning (ML) on spectroscopic imagery (SI) from NASA’s Airborne Visible and Infrared Imaging Spectrometer Next Generation (AVIRIS-NG) yields accurate maps of grapevine leafroll-associated virus 3 (GLRaV-3) at multiple spatial resolutions. Providing these maps to agricultural stakeholders would reduce time, expenses, and uncertainty associated with management, however, both storing SI and training/deploying ML models require significant computing and storage resources. This challenge will magnify tenfold as global SI from the forthcoming satellite Surface Biology & Geology satellite becomes available. We present a cloud-native architecture for plant disease detection to address this challenge using SI from NASA's AVIRIS-NG with GLRaV-3 as a model system. Our system processes SI into disease incidence maps using simple ML (Random Forest, optimized through SMOTE) and easily accommodates new additions and improvements, as well as shifting data modalities, without retaining potentially proprietary stakeholder information. We present an innovative system that empowers stakeholders to make data-driven plant disease management decisions informed by cutting-edge SI while preserving reproducibility and user privacy.

CLASSIFICATION OF SOUTHERN CORN RUST SEVERITY BASED ON LEAF-LEVEL HYPERSPECTRAL DATA COLLECTED UNDER SOLAR ILLUMINATION

JIANMENG G. (1), YUE M. (1), **ZHANHONG M. (1)**

(1) Department of Plant Pathology, China Agricultural University, Beijing, CHINA

Maize is one of the most important crops in China, and it is under a serious, ever-increasing threat from southern corn rust (SCR). SCR has spreaded northward to northeast China, causing severe yield loss. Thus, a cost-effective, real-time detection method is required. The identification of wheat rust based on hyperspectral data has been proved effective. For SCR research, the reliability and usability of spectra collected under solar illumination (SCUSI) need to be explored. In this study, full-range hyperspectral data (350~2500 nm) were collected under solar illumination, and SCUSI were separated into several groups according to the disease severity, measuring height and leaf curvature. Ten indices were selected as candidate indicators for SCR classification, and their sensitivities to the disease severity, measuring height and leaf curvature, were subjected to analysis of variance (ANOVA). The better-performing indices according to the ANOVA test were applied to a random forest classifier, and the classification results were evaluated by using a confusion matrix. The results indicate that the PRI was the optimal index for SCR classification based on the SCUSI, with an overall accuracy of 81.30% for mixed samples. The results lay the foundation for SCR detection in the incubation period and reveal potential for SCR detection based on UAV and satellite imageries, which may provide a rapid, timely and cost-effective detection method for SCR monitoring.

QUANTITATIVE INVERSION OF WHEAT STRIPE RUST DISEASE INDEX BASED ON UNMANNED AERIAL VEHICLE HYPERSPECTRAL IMAGERY AND PIXEL-LEVEL REGRESSION ALGORITHM

JIE D. (1), JUNZHENG S. (1), **ZHANHONG M. (1)**

(1) Department of Plant Pathology, China Agricultural University, Beijing, CHINA

There have been many research achievements in the detection of wheat stripe rust disease based on UAV multispectral/hyperspectral remote sensing images and deep learning methods. In this study, 1,920 local wheat varieties were selected as experimental materials in Henan Province, with a planting area of 13,350 square meters. High-resolution hyperspectral images were obtained by drones at a height of 100 meters at different infection stages. Deep learning methods were used to achieve end-to-end quantitative inversion of disease index by adding a Sigmoid activation function and using continuous loss functions such as Laplacian Loss. The study also compared the model performance with different loss functions, model architectures, with or without the addition of the PSA module, and different datasets. The results showed that the LaplacianLoss+MSELoss loss function and the HRNet_W18 algorithm model had the best performance, with an R2 of 0.875 and a mean average error (MAE) of 0.0129 on the test set. After adding the PSA module, the R2 reached 0.880, and the MAE was 0.0123. When using a few feature indices for modeling (such as 6 feature indices modeling), the model recognition effect decreased significantly to 0.829 compared to the full-band modeling. The results showed that end-to-end modeling based on deep learning algorithms can be directly carried out on the full band to reduce data analysis steps and achieve better inversion effects.

LIST OF REGISTERED ATTENDEES

This list reflects all registered attendees as of 10th July 2023.

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