Whither (or wither) Plant Pathology in the next 50 years?

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SASPP

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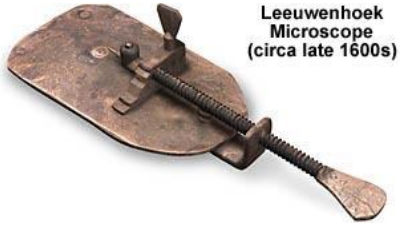
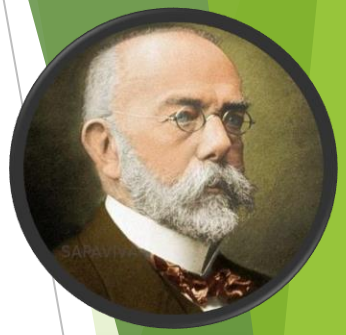
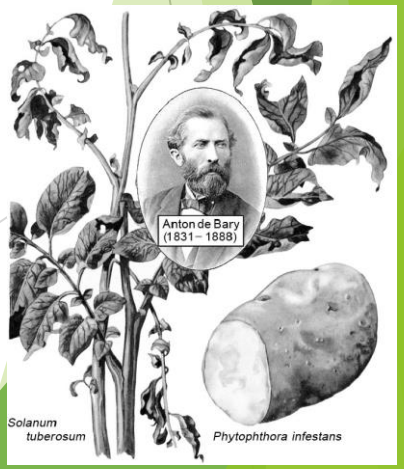
YUNIVESITHI YA FREISTATA

National Science and Technology Forum

A Time Line of Plant Pathology







286 BC — Theophrastus, the father of botany, studied diseases of trees, cereals and legumes.

1665 — Robert Hooke illustrates a plant-pathogenic fungal disease, rose rust.

1675 — Anton van Leeuwenhouek invents the compound microscope, in 1683 describes bacteria seen with the microscope.

1802 — Lime sulfur first used to control plant disease .

1845-1849 — Potato late blight epidemic in Ireland.

1853 — Anton de Bary, father of modern mycology, establishes that fungi are the cause, not the result, of plant diseases.

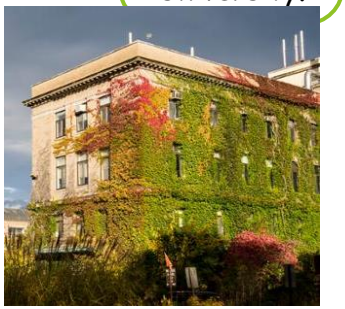
1879 — Robert Koch establishes germ theory: diseases are caused by microorganisms.

A Time Line of Plant Pathology

1885 — Proof that bacteria can cause plant diseases: "*Erwinia amylovora* " and fire blight of apple.

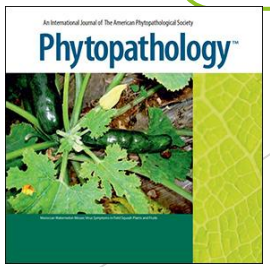
1886 – 1898 — Recognition of plant viral diseases: Tobacco mosaic virus.

1903 — First academic dept of plant pathology established, at U. of California under Prof Ralph E. Smith.



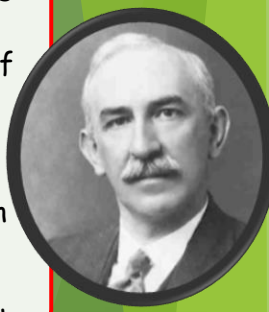
1907 — First academic dept of plant pathology established at Cornell University.

1908 — American Phytopathological Society founded.



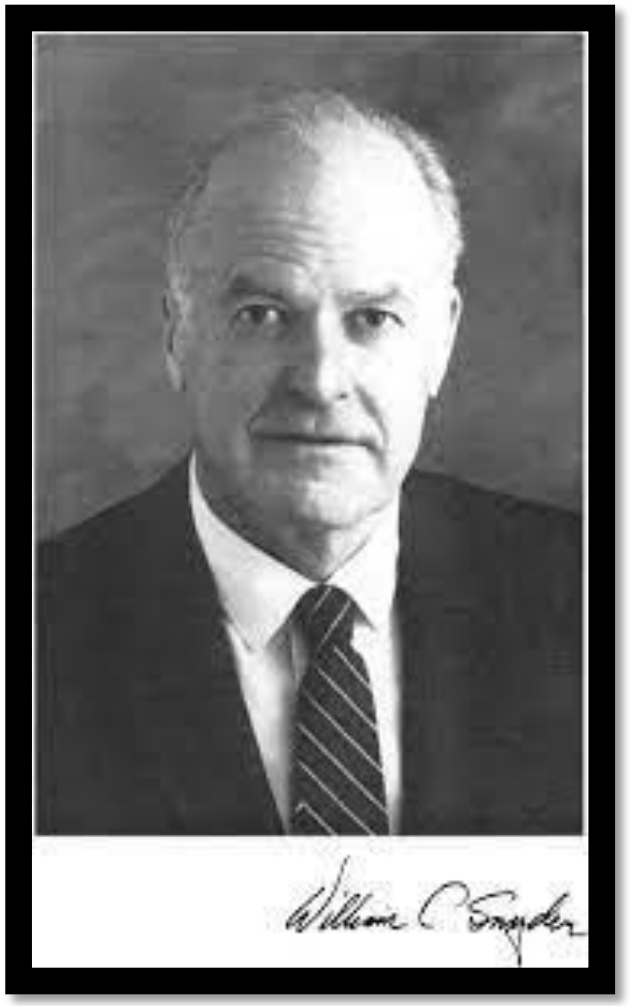
1911 — Scientific journal Phytopathology founded.

1921 — Paul A. van der Bijl appointed as the first Professor of Plant Pathology and Mycology in South Africa, at Stellenbosch University



1962 — SASPP founded

50 years ago in 1971…..



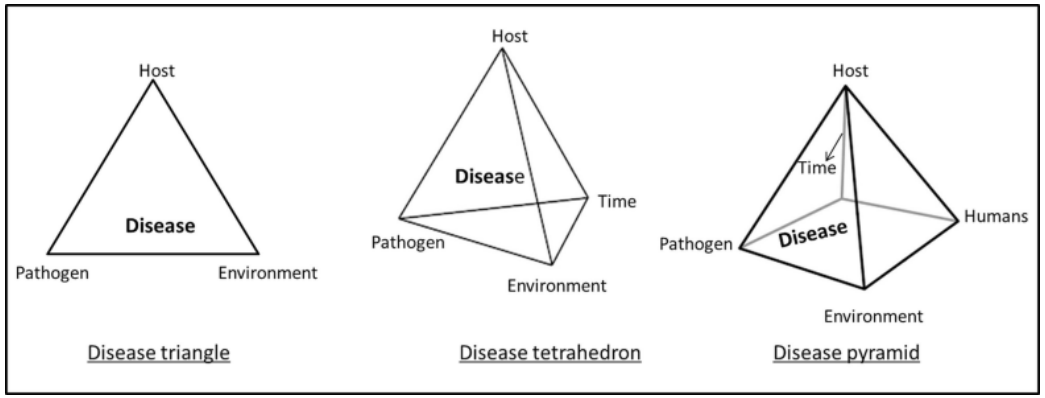
PLANT PATHOLOGY TODAY

WILLIAM C. SNYDER
Department of Plant Pathology
University of California

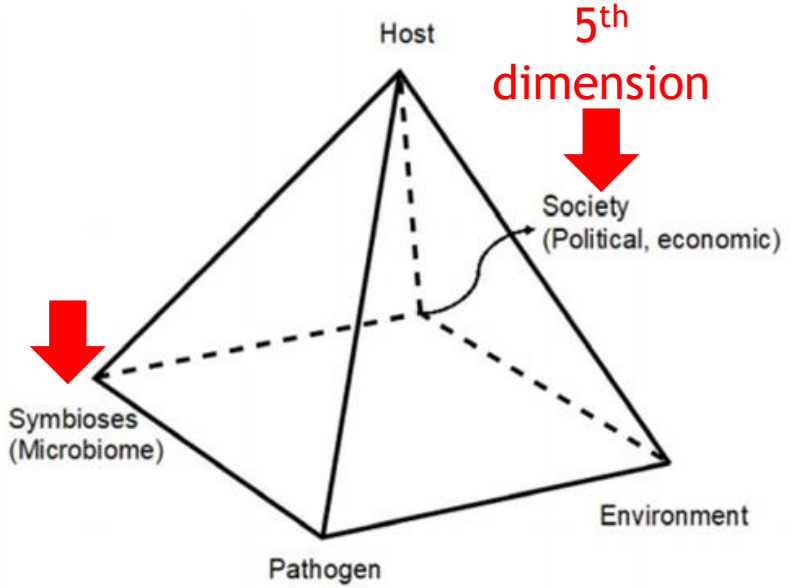
Annual Review of Phytopathology 1971: 9:1-7

- "**Today the Sciences, including Plant Pathology, and even the Universities are in trouble.** Troubled times are continuous and current troubles always seem the most serious.
- **Terms such as "agriculture" and "plant pathology" are a bit "out," while "ecology" and "environment" are "in."** Yet actually the concerns of the latter terms are built into plant pathology.
- Our discipline more than most others is concerned with the inter-relationships of the pathogen and host, ecologically and in relation to the total environment.
- **No other discipline is more concerned with ecology and the environment. If the public really knew about us, we should be "in." "**

Plant Disease: Old and New Concepts



Marchand G., Nicot P.C., Albajes R., Carisse O. (2020) Epidemiology and Population Dynamics: Modelisation, Monitoring and Management. In: Gullino M., Albajes R., Nicot P. (eds) Integrated Pest and Disease Management in Greenhouse Crops. Plant Pathology in the 21st Century, vol 9. Springer, Cham.



Slippers B. 2020. The Plant Disease Pyramid: The relevance of the original vision of plant pathology in 2020. S Afr J Sci. 116(11/12)

"…. fifth dimension…..will have profound impact on disease development and outcomes on scales from the local to the global."

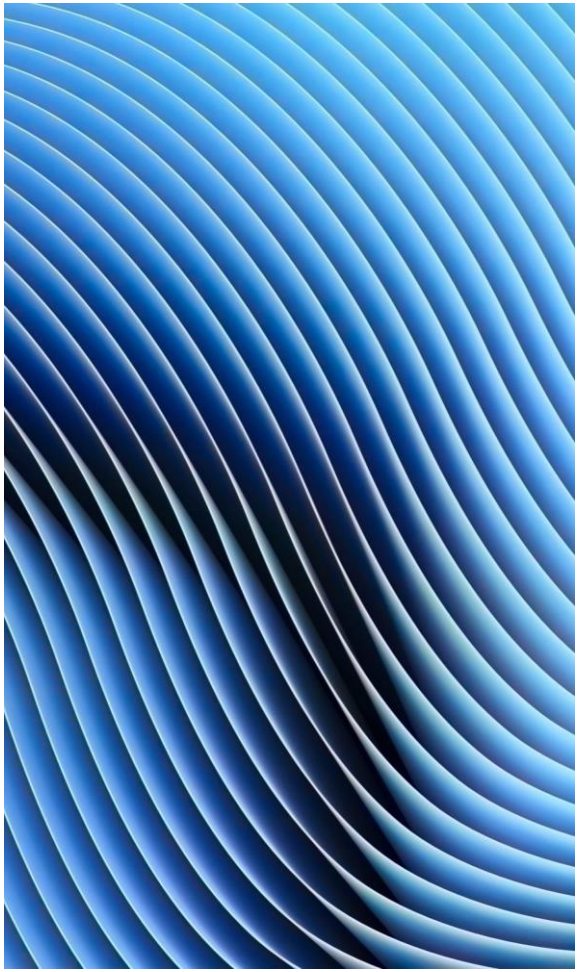
"…. the aim of plant pathologists, in collaboration with other fields and sectors of society, should be a continuously adaptive and resilient system that can buffer against shocks such as pandemics….."

Plant Pathology:

Future Challenges

- Increasing demand for food to support the booming global population and its improving living standards;
- Reducing production potential in agriculture due to competition for land in fertile areas and exhaustion of marginal arable lands;
- Increased risk of disease epidemics resulting from agricultural intensification and monocultures.
- Deteriorating ecology of agro-ecosystems and depletion of natural resources;
- Influence of climate change on the complex interactions between plants and pathogens.

A Sustainable Future Strategy for Plant Pathology…



Must be based on the use of one or more renewable resources.

Does not break down due to evolutionary change.

Has a broad spectrum of applicability.

Is affordable in the context of the local economy and crop value.

CRUTE, I. R. (2003). Increased crop productivity from renewable inputs – a scientific challenge for the 21st century. Proceedings of an International Congress held at the SECC, Glasgow, Scotland, UK, 10–12 November 2003, pp. 3–14. Alton, UK: BCPC.

Key issues facing plant pathologists in the 21st century:

1. To strengthen food security while simultaneously safeguarding the health of associated ecosystems and reducing dependency on natural resources.

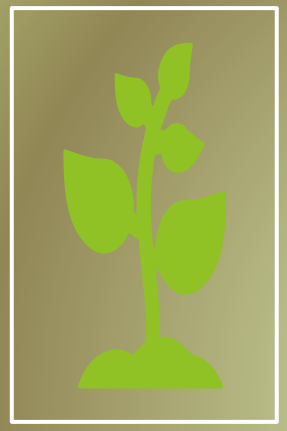
2. To devise pest and disease control systems that are sustainable and not compromised by the evolution of pest and pathogen strains able to overcome crop resistance or chemicals.

3. To develop appropriate crop protection technologies, as well as mechanisms for their use, in low-input farming systems.

Lucas, J.A. 2011. Advances in plant disease and pest management. Jnl of Agricultural Science 149, 91–114.

Future Technologies

Disease Detection and Diagnosis



Plant Defence and Immunity

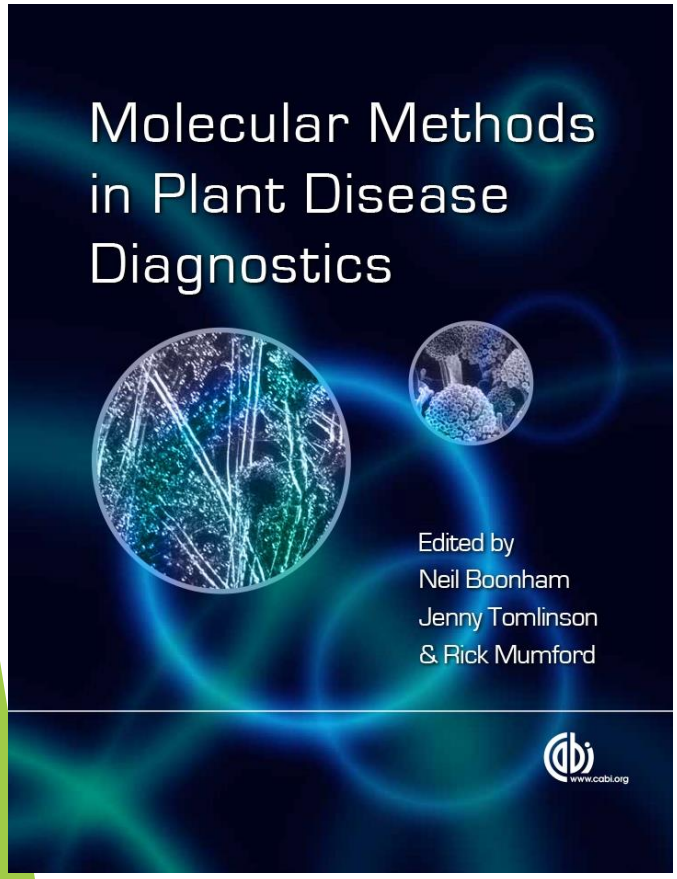
Accessing and Exploiting Genetic Diversity

Pathogen Targets for Intervention

Ecological Approaches to Disease Control

Lucas, J.A. 2011. Advances in plant disease and pest management. Jnl of Agricultural Science 149, 91–114.

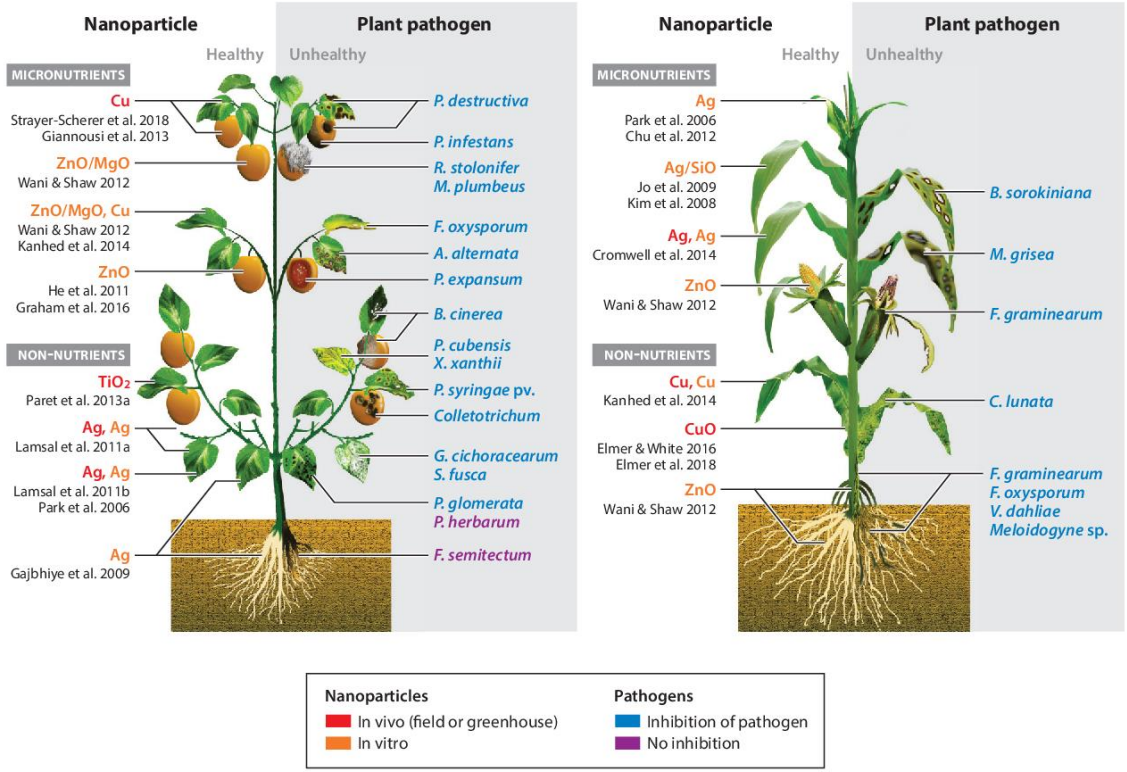
1. Disease Detection and Diagnosis: Molecular diagnostics



- DNA-based technologies have greatly increased the speed, sensitivity and accuracy of pest and pathogen detection and diagnosis.
- The development of biosensors able to identify pathogen inoculum in real time, coupled to information networks will provide real-time monitoring and surveillance of crops or stored produce.
- This will give early warning of emerging problems and new invasive species.

Nanotechnology

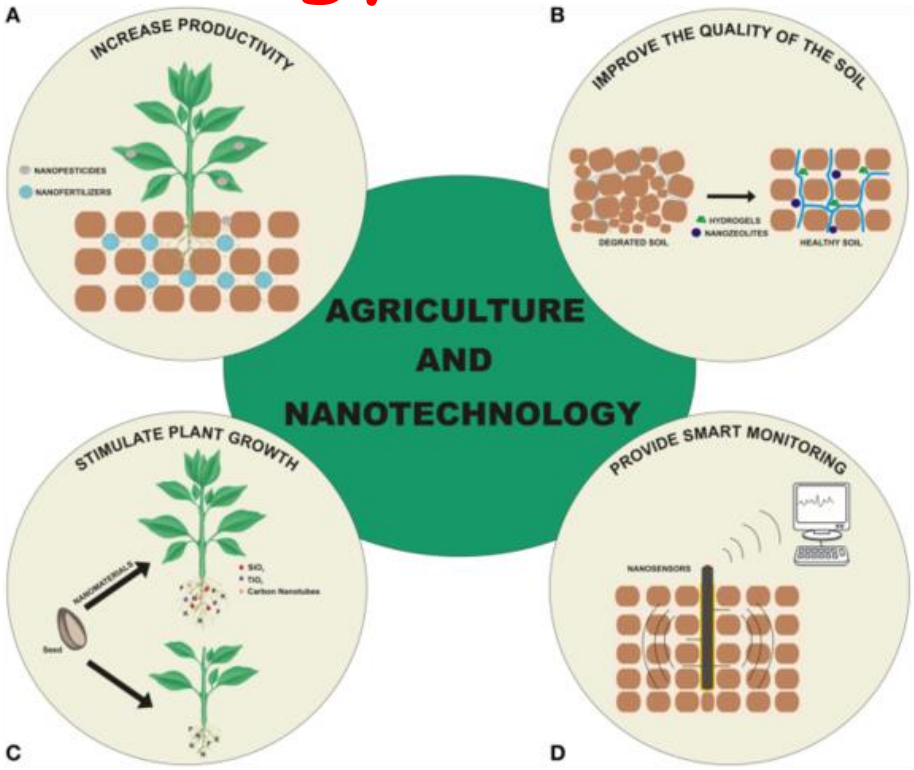
- In the past decade, reports of nanotechnology in phytopathology have grown exponentially.



- Nanomaterials have been integrated into disease management strategies and diagnostics and as molecular tools.

M. Gaspar, Olga A Lastovetsky, A. Bombarely, M. Goodin. 2018. The Future of Nanotechnology in Plant Pathology. Annu. Rev. Phytopathol 56 :111-133

Nanotechnology can ….



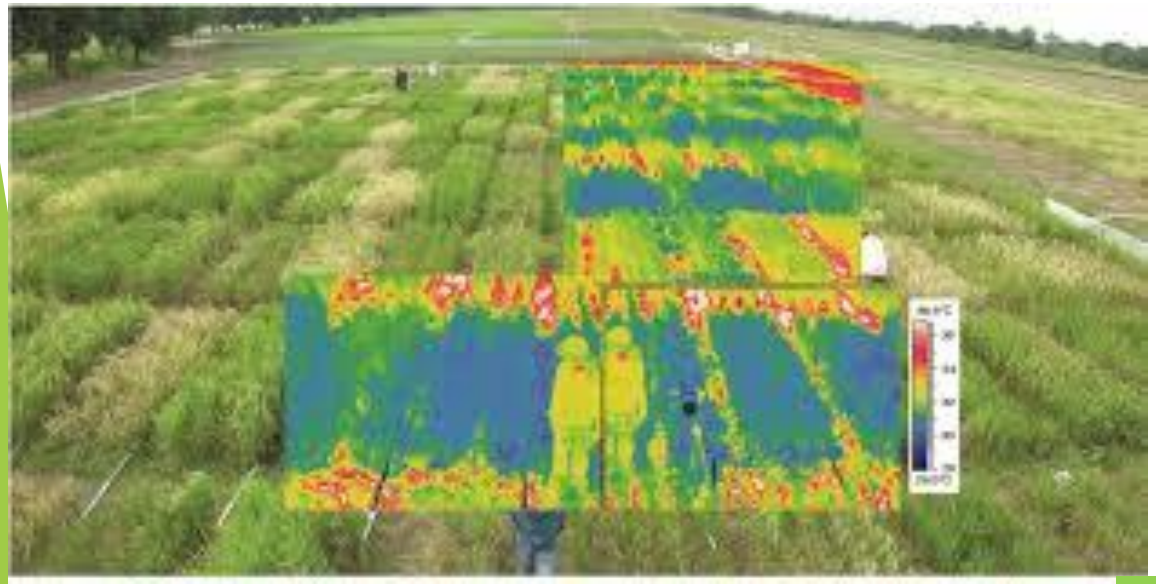
- A. Increase the productivity using nanopesticides and nanofertilizers;
- B. Improve the quality of the soil using nanozeolites and hydrogels;
- C. Stimulate plant growth using nanomaterials (SiO_2, TiO_2, and C-nanotubes);
- D. Provide smart monitoring via nanosensors and wireless communication devices.

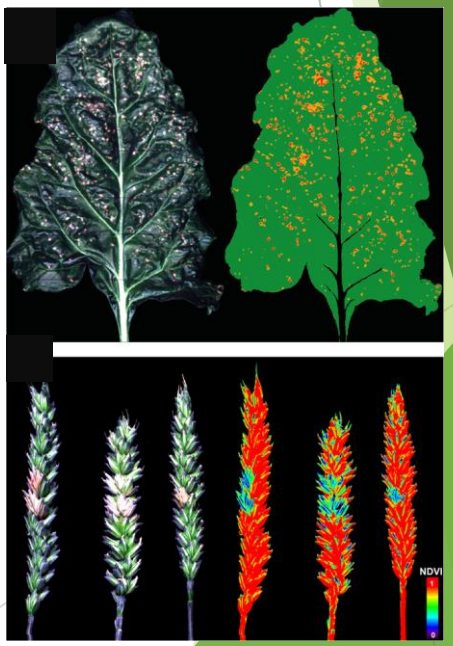
Fraceto LF, Grillo R, de Medeiros GA, Scognamiglio V, Rea G and Bartolucci C 2016. Nanotechnology in Agriculture: Which Innovation Potential Does It Have? Front. Environ. Sci. 4:20.

1. Disease Detection and Diagnosis: Remote Sensing

- Hyperspectral technology-based plant disease detection, as a typical type of non-invasive technology, is drawing increasing attention by precision agriculture.

- Web of Science: found 651 relevant papers from 1990-2019 when "plant disease" and "hyperspectral" used as the key words to search for in "all databases."



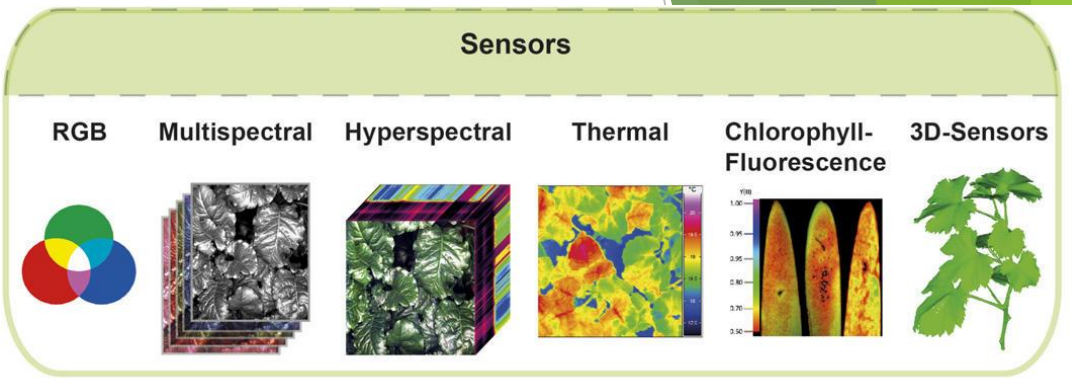


Remote Sens. 2020, 12: 3188

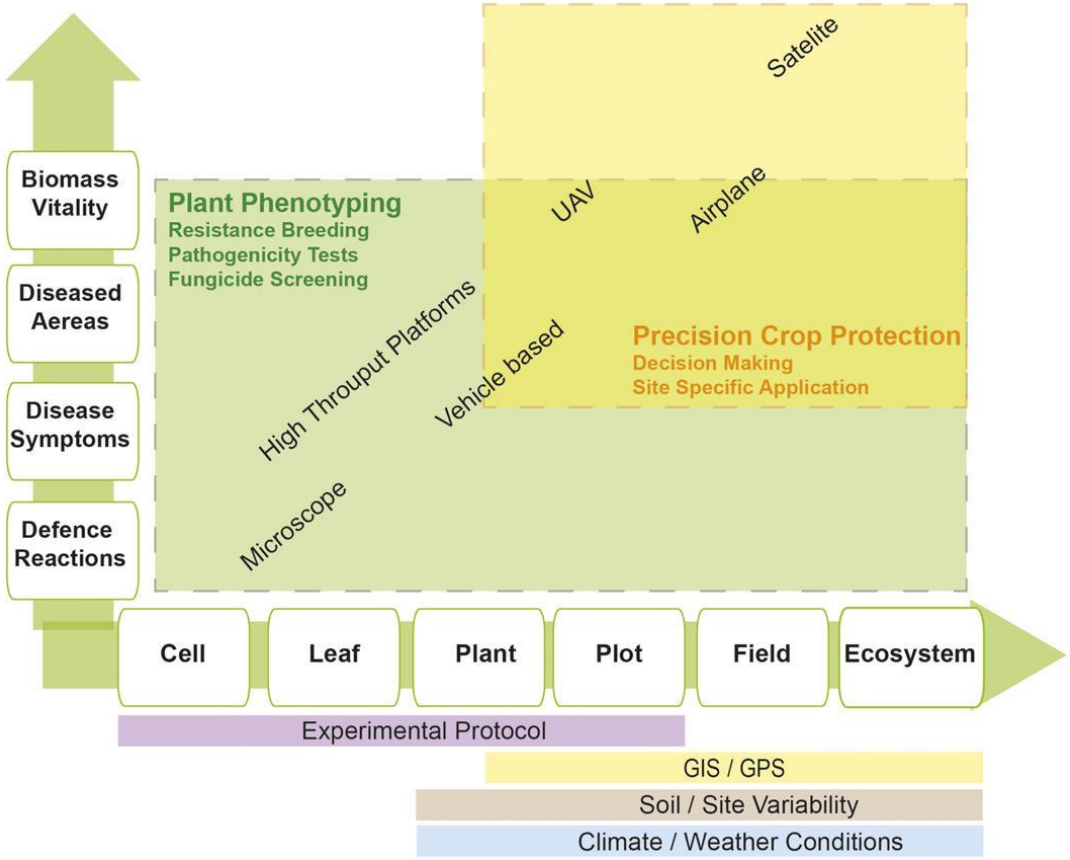
Anne-Katrin Mahlein 2016. Plant Disease 100: 241-251

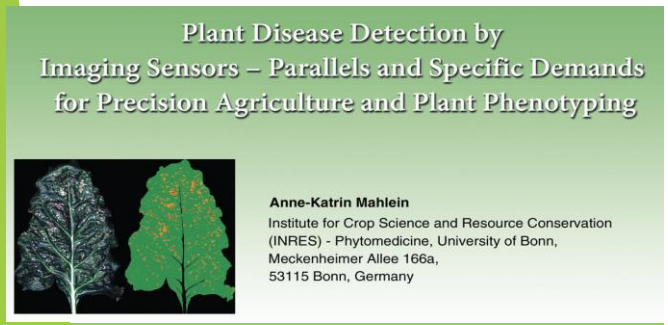
Sensor Technologies

Current sensor technologies used for the automated detection and identification of host-plant interactions.



Sensors can be implemented in precision agriculture applications and plant phenotyping on different scales from single cells to entire ecosystems.





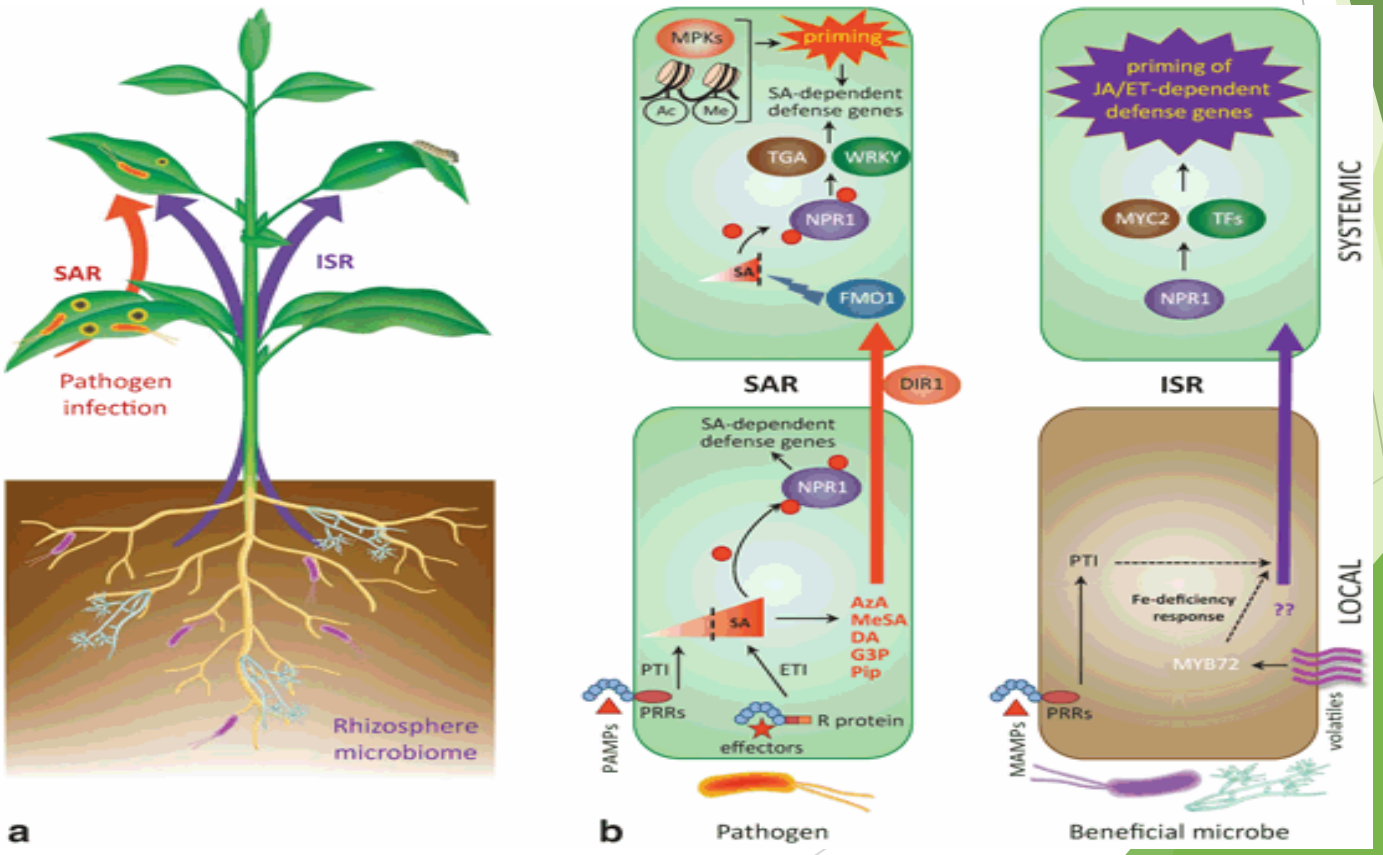
Anne-Katrin Mahlein 2016. Plant Disease 100: 241-251

2. Plant Defence and Immunity

Induced plant resistance

- Improved exploitation of induced plant resistance by 'tuning' or priming plant defences to deal with a diversity of biotic and abiotic stress.

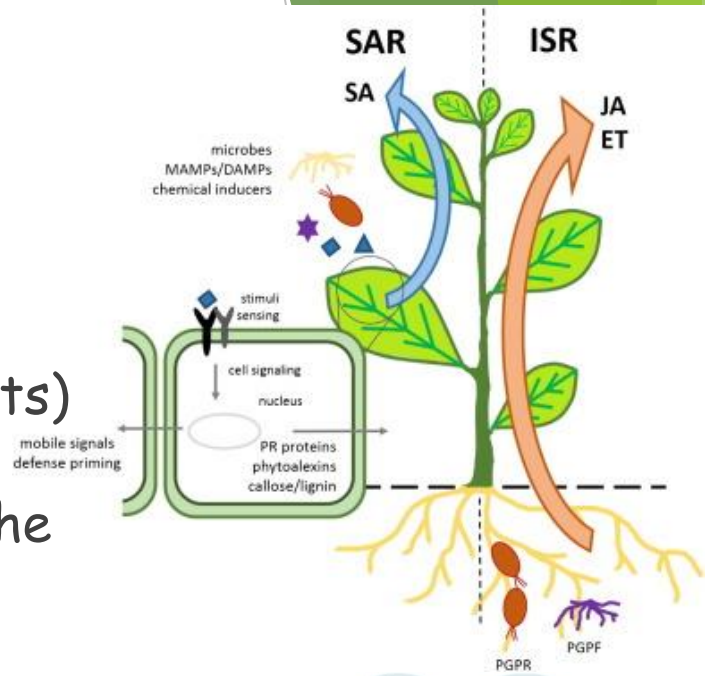
- SA, JA and ET signalling pathways are potentially antagonistic, but the emerging view is that synergy can be achieved between these parts of the plant defence network to achieve broad-spectrum resistance to pests and pathogens.



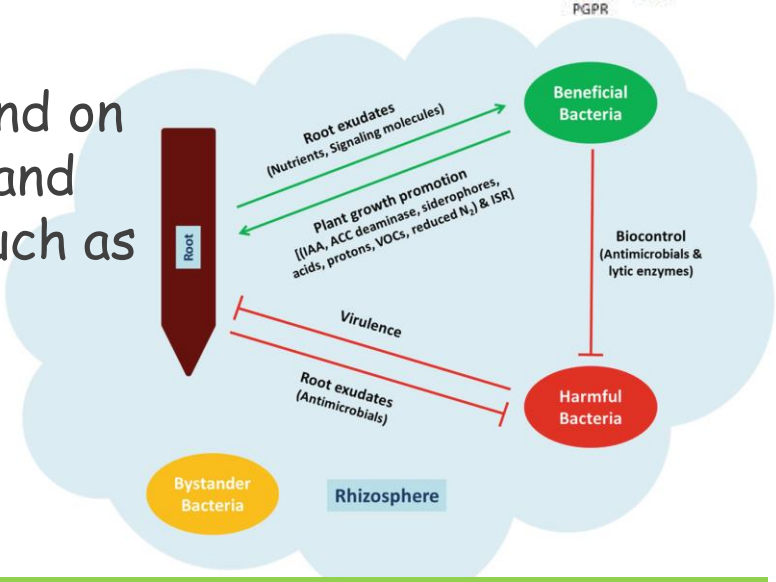
2. Plant Defence & Immunity

Plant defence activators

- Future prospects of delivering chemicals modulating plant resistance via biological agents, (such as engineered microbial colonists) might lend themselves to low-cost seed or propagation material treatments, removing the need for expensive spray regimes.



- The success of such approaches will depend on improved knowledge of microbial ecology and population dynamics in microbiomes, as much as on the role of specific signal molecules.

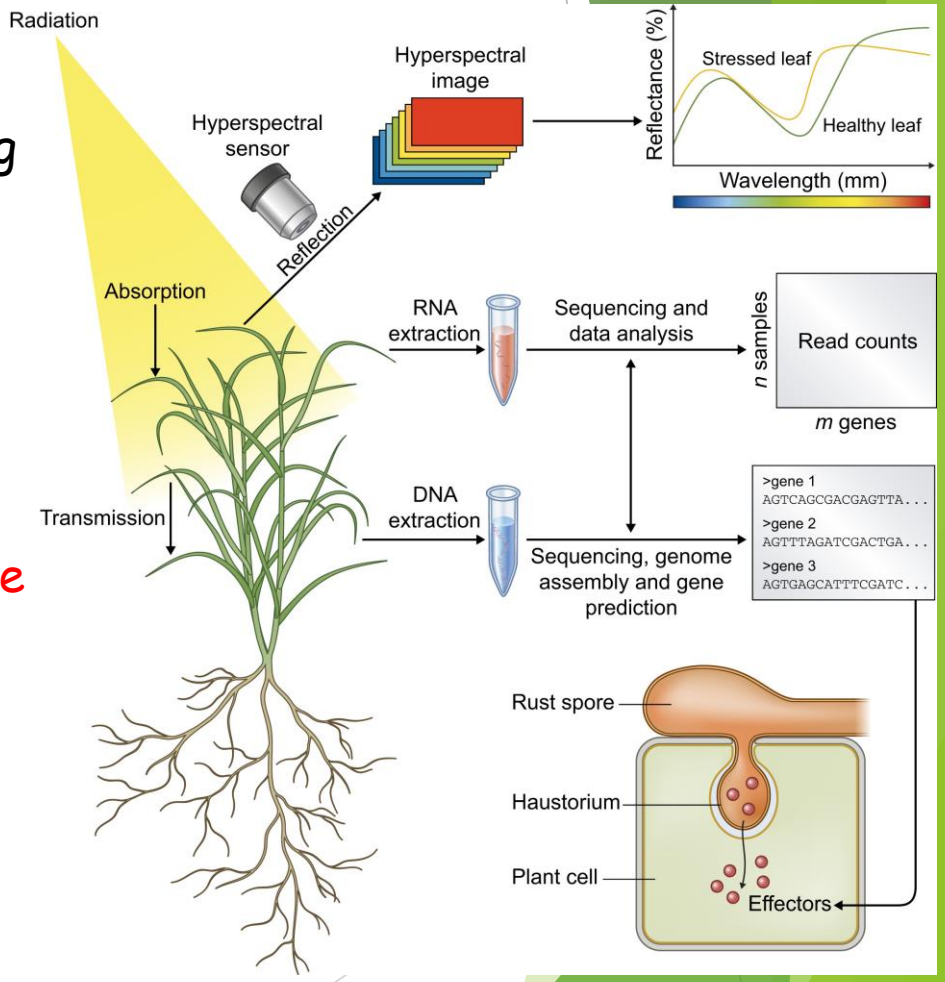


Vukanti R.V.N.R. (2020) Structure and Function of Rhizobiome. In: Varma A., Tripathi S., Prasad R. (eds) Plant Microbe Symbiosis. Springer, Cham.

Machine learning in plant–pathogen interactions

Machine learning (ML): the application of statistical methods to identify patterns in data, commonly divided into unsupervised and supervised approaches.

- Light reflectance from a healthy rice plant leaf will differ from that of a stressed leaf and can be measured using sensors.
- Stressed and healthy leaves will display distinct reflectance curves.
- By sequencing pathogen or plant genomes, one can pinpoint genes that are involved in host-pathogen interactions.
- ML can enable prediction of pathogen proteins that enter plant cells (cytoplasmic effectors).



Jana Sperschneider, 2019. Machine learning in plant–pathogen interactions: empowering biological predictions from field scale to genome scale. New Phytologist, Volume: 228, Issue: 1, Pages: 35-41

3. Accessing and Exploiting Genetic Diversity

Genetic Diversification

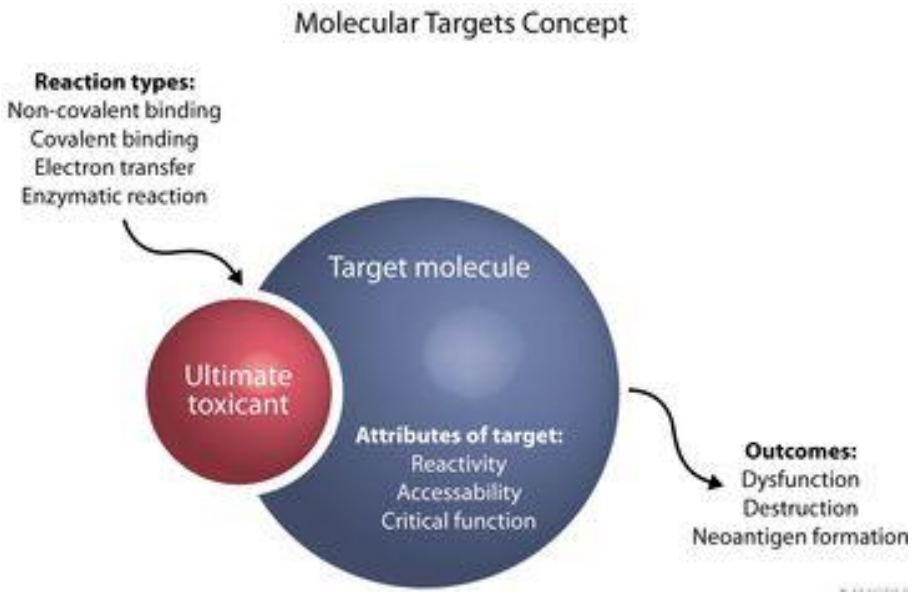
- Sequencing of the genomes of the major crop species and their wild relatives will expand the known gene pool and diversity of genetic resources available for plant breeders to access.

Genetic Modification (GM)

- GM approaches will facilitate pyramiding resistance genes in crops with different specificities and modes of action, thereby reducing the risk of directional selection for virulence by pathogens.

4. Pathogen Targets for Intervention

- A new era beckons where the prospect of 'crop pharmacology' based on signal molecules and their receptors will become a reality.



- It will be based on the development of new chemistries designed to manipulate specific molecular targets, either in regulating host resistance, or disabling the disease-causing processes of pathogens.

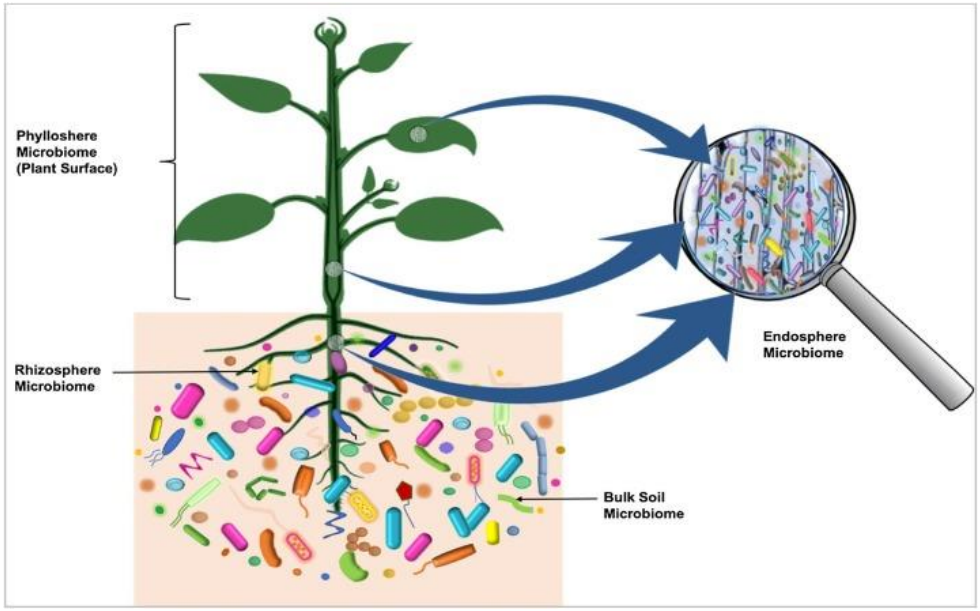
- It will be driven by an exponential increase in genomic, transcriptomic, proteomic and metabolomic information populating databases, and improving the tools to manage, mine and interpret this information.

5. Ecological Approaches to Disease Control

- Understanding the ecology of pathogens will improve our ability to exploit their natural enemies or antagonists.

  - Insights into the natural diversity and activity of soil and microbial populations in microbiomes will provide information on mechanisms of suppression regulating pest species.

  - Manipulation of microbiomes thereby recruiting and retaining more effective microorganisms for biocontrol, biofertilizers, etc.

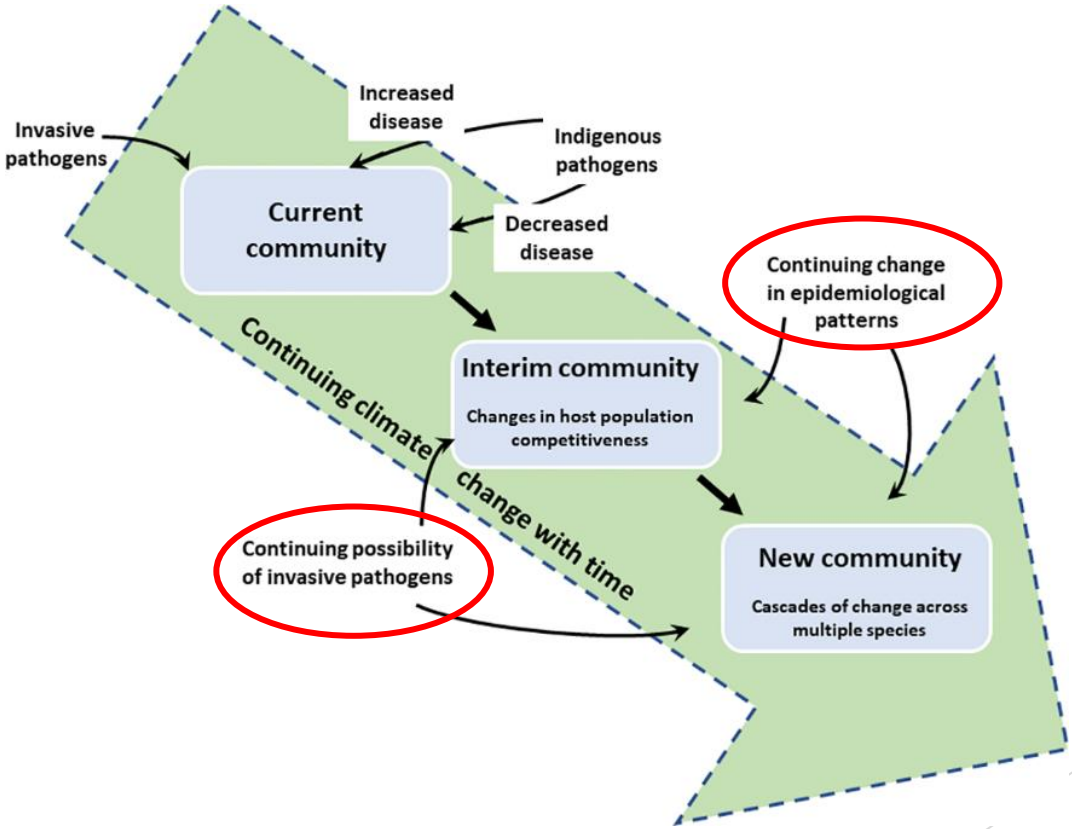


- Volatile organic compounds (VOC's), either from natural plant sources or engineered in transgenic crops, will be used to modify pathogen behaviour.

Dun-chun, et al., 2016. Problems, challenges and future of plant disease management: from an ecological point of view. *Journal of Integrative Agriculture 15(4): 705–715*

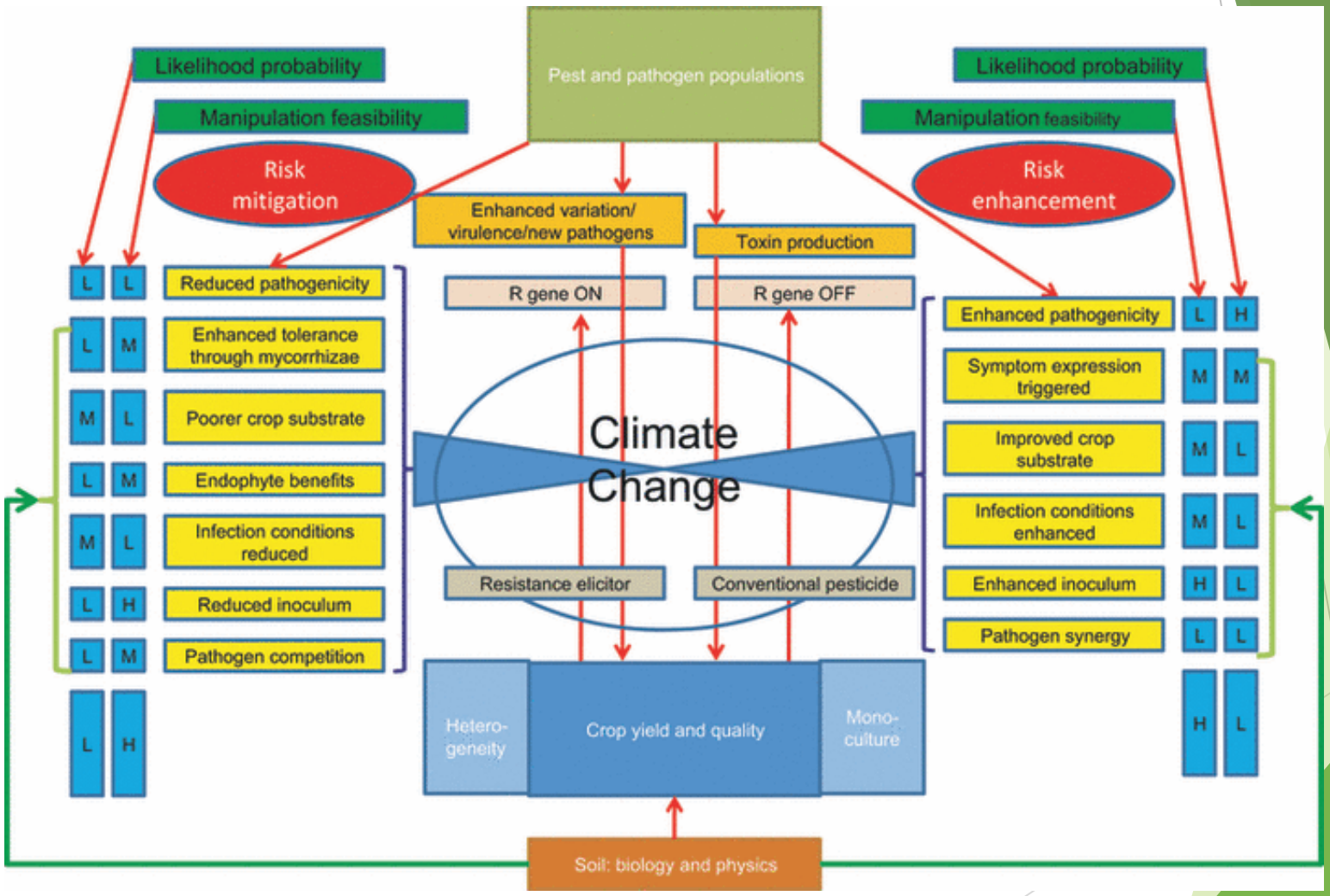
5. Ecological Approaches to Disease Control

The introduction of invasive pathogen species and the effects of climate change will have a particular impact on emerging plant diseases and managing epidemics.



Burdon JJ, Zhan J (2020) Climate change and disease in plant communities. PLoS Biol 18(11)

Influence of climate change on rate-determining processes that are the result of the complex interactions between the 'enhancing' and 'mitigating' influences on plant and pest/pathogen interactions.



Plant Pathology (2011) 60, 2-14

5. Ecological Approaches to Disease Control

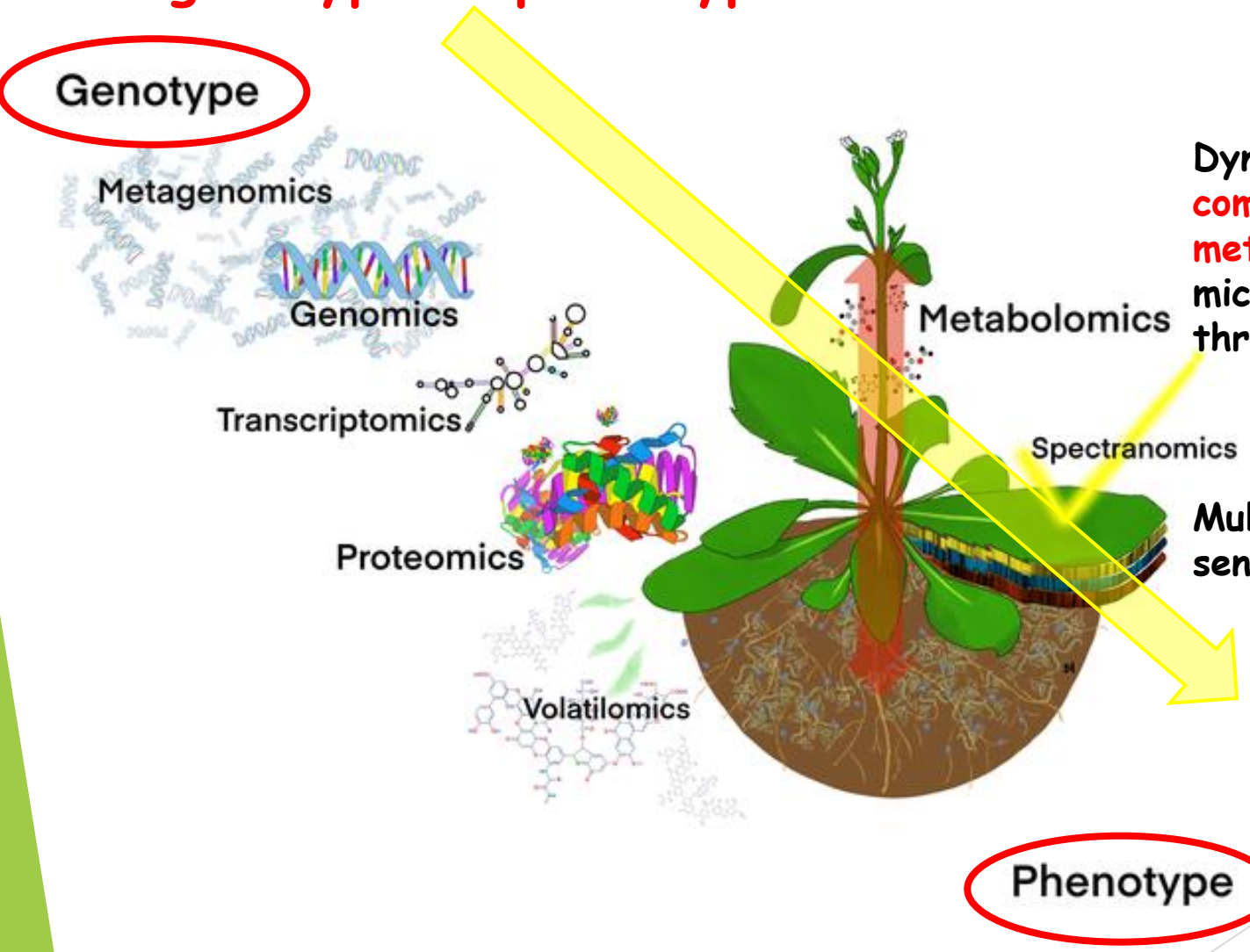
- It is therefore critical to take a holistic approach to understand how and why pathogenesis occurs in order to effectively manage for diseases given the synergies of changing environmental conditions.

- A multi-omics approach allows for a detailed picture of plant-microbial interactions and can ultimately allow us to build predictive models for how microbes and plants will respond to stress under environmental change.

- ***Omics* approaches** from the genotype to the phenotype will inform plant disease ecology in a holistic manner and can shed light on microbial communities above and belowground.

Crandall SG, Gold KM, Jiménez-Gasco MdM, Filgueiras CC, Willett DS (2020). A multi-omics approach to solving problems in plant disease ecology. PLOS ONE 15(9)

Multi-omics approaches inform the genotype to phenotype cascade.

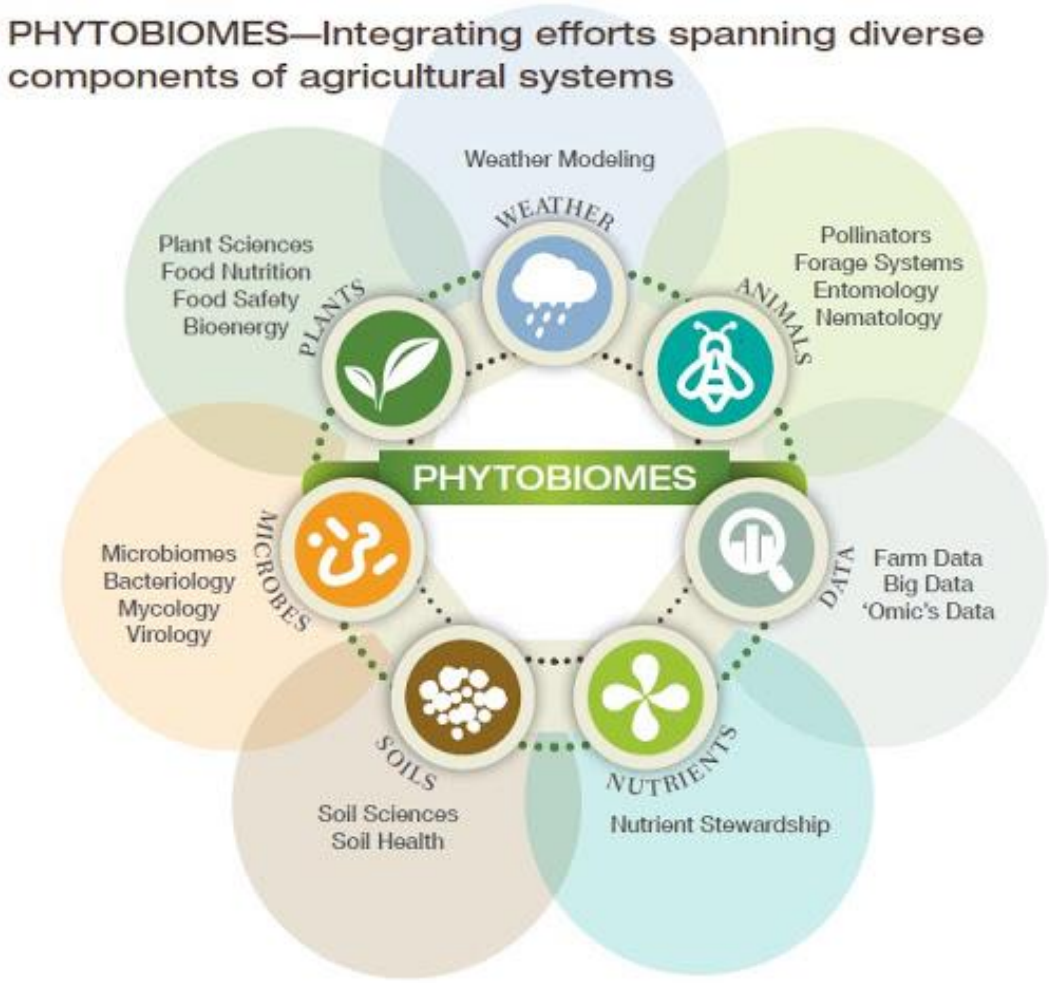


Dynamic intra-plant communication in the metabolome affecting microbial communities through released VOC's.

Multiple bands of sensing (below leaf).

Crandall SG, Gold KM, Jiménez-Gasco MdM, Filgueiras CC, Willett DS (2020). A multi-omics approach to solving problems in plant disease ecology. PLOS ONE 15(9)

Towards a Systems Thinking Approach



Phytobiomes consist of plants, their environment, and their associated communities of organisms.

A systems-level understanding of phytobiomes will enable us to sustainably and profitably produce sufficient crops to meet global demands while minimizing negative impacts on the environment.

A Systems Thinking Approach…..
to deal with an approaching Perfect Storm…..

- Future epidemiology must bridge scales from a genetic to a global level.
- The catalyst for this interdisciplinary approach is the application of mathematical modelling that can be used successfully to capture the complexities of the host–pathogen–environment interactions.

Major opportunities:

1. An unprecedented capacity to gather and analyse 'big data'.
2. Anti-microbial resistance (AMR) has the potential to cause epidemics not experienced since the pre-antibiotic era.
3. Epidemiological models therefore need to merge with an economic and behavioural framework.

Kleczkowski A, Hoyle A, McMenemy P. 2019. One model to rule them all? Modelling approaches across One Health for human, animal and plant epidemics. Phil. Trans. R. Soc. B 374: 20180255.

Educating Future Plant Pathologists…..

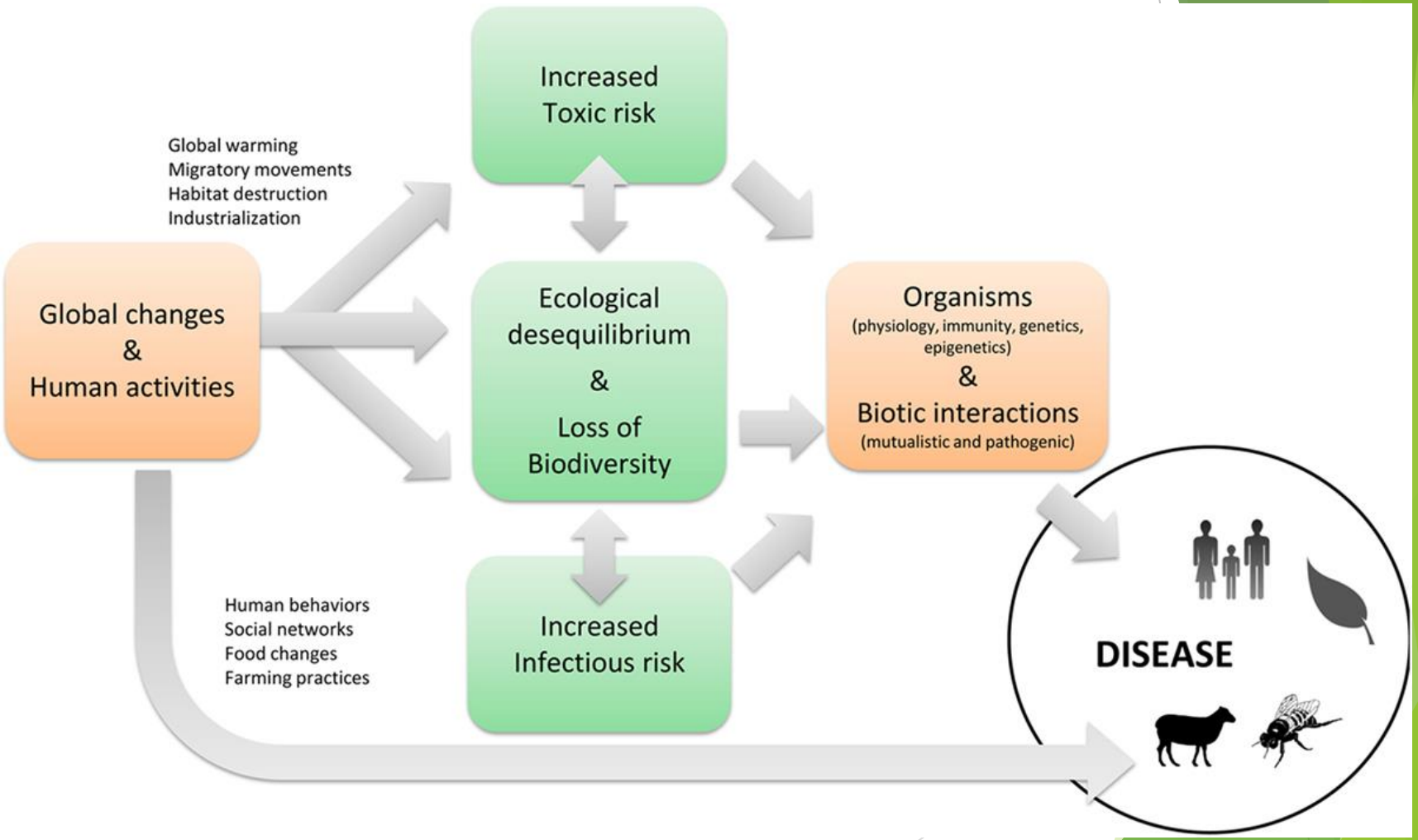
Lack of health integration across human, animal, plant, and environmental health sectors calls for the creation of a One Health Worker.

MacDonald, et al., 2009. "Education in Plant Pathology Present Status and Future Challenges". *Papers in Plant Pathology*. 322.

Wilkes, M. et al., 2019. One Health workers: innovations in early detection of human, animal, and plant disease outbreaks

The One Health Concept

One Health (OH): Represents the collaboration of multiple disciplines working to achieve optimal health for people, animals, plants/crops, and environment.



Destoumieux-Garzón D, et al., 2018. The One Health Concept: 10 Years Old and a Long Road Ahead. Front. Vet. Sci. 5:14.

Interdisciplinary Research:
Understanding complexity in a time of crisis

How can interdisciplinary thinking help us study and understand problems that cross disciplinary boundaries?

Working beyond a single discipline:

Multi-disciplinary

- Relating to, or making use of several disciplines at once

Cross-disciplinary

- Coordinating efforts or approaches by involving two or more disciplines

Inter-disciplinary

- Integrating concepts, frameworks or approaches two or more disciplines, fields of study or professions

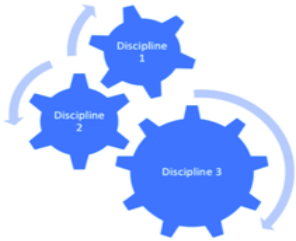
Trans-disciplinary

- Thinking that transcends boundaries of conventional disciplines

Independent disciplines

Involves sequenced and focused content with discipline-based correlated ideas

Multidisciplinarity



Contrasts disciplinarity perspectives in an additive manner, involving little interaction between disciplines

Interdisciplinarity

Combines two or more disciplines to a new level of integration, beginning to break boundaries

One Health = A Systems Thinking Approach

The integration of a wide range of disciplines, including systems engineering, biogeochemistry, genomics, biochemistry, physiology and ecology, will all be required components of this complex cocktail.

Human

1. Provide basic health advice on select primary care health conditions;
2. Promote early detection of human endemic or epidemic health threats;
3. Document the water and food sources and food-storage/preparation and identify overlap with animal and plant health;
4. Collect information at the household level, on sewage disposal of human, animal, and crop waste;
5. Document the use of pesticides and potential environmental toxins; and,
6. Collect data to identify health care gaps in community human, animal, and plant/crop health.

Animal

1. Improve overall animal health thereby family economic health;
2. Provide geo-linked community-based mapping of common animal disease problems to facilitate early detection and intervention of emerging and re-emerging animal pathogen and disease threats;
3. Improve food security and monitor for food-borne illness;
4. Reduce inappropriate antibiotic use; and,
5. Integrate animal, plant/crop, and human disease problems at the data output and collection level.

Plant/Environment

1. Understand agricultural practices, water use, planting and storage of crops;
2. Establish symptoms for early identification of plant/crop diseases
3. Document pesticides, fertilizers, and toxins used for crop agriculture, including organic methods
4. Identify and document common pathogens, Infestations, or growth disorders of crops; and,
5. Provide geo-linked community-based mapping of common agricultural problems to enable early detection and intervention.

Wilkes, M. et al., 2019. One Health workers: innovations in early detection of human, animal, and plant disease outbreaks

SAVE THE DATE

ICPP 2023

ONE HEALTH
for all plants, crops and trees

20-25 August, France

Whither or wither Plant Pathology?

What does the future hold for plant pathology?

A Futuristic Perspective

Collaborations with biomedical and aeronautical engineers, nanotechnologists, and computer scientists will help develop micro-sensory technology for the detection of new pathogens for use in biosecurity, diagnostics and epidemiological modeling.

Perhaps in the not-too-distant future there will be a plant disease Tricorder©, like the one used by Dr. McCoy in Star Trek.

An instrument that contains a DNA chip from virtually every known plant pathogen where we can simply snip off a piece of the infected plant material, slip it into the 'Tricorder©' and, within seconds, we not only have the diagnosis of the disease, but all the information about its control too.

Far fetched, perhaps, but no doubt possible….

SASPP

Thanks for your attention!

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