INTERNATIONAL YEAR OF PLANT HEALTH 2020

The Plant Disease Pyramid: The relevance of the original vision of plant pathology in 2020

AUTHOR:
Bernard Slippers[1,2]

AFFILIATIONS:
[1]Department of Biochemistry, Genetics and Microbiology, University of Pretoria, Pretoria, South Africa
[2]Forestry and Agricultural Biotechnology Institute (FABI), University of Pretoria, Pretoria, South Africa

CORRESPONDENCE TO:
Bernard Slippers

EMAIL:
bernard.slippers@fabi.up.ac.za

HOW TO CITE:
Slippers B. The Plant Disease Pyramid: The relevance of the original vision of plant pathology in 2020. S Afr J Sci. 2020;116(11/12), Art. #9011, 3 pages. https://doi.org/10.17159/sajs.2020/9011

ARTICLE INCLUDES:
☐ Peer review
☐ Supplementary material

KEYWORDS:
Disease Triangle, plant health, climate change, emerging pathogens, societal factors

PUBLISHED:
26 November 2020

In 1926, Professor Paul A. van der Bijl made an address to the South African Association for the Advancement of Science in his capacity as President of Section C of the Association, entitled 'Landmarks in the development of the science of plant pathology and of disease control'.[1] The talk itself marks a key moment in the development of plant pathology as a discipline in South Africa, as Van der Bijl had been appointed 5 years earlier as the first Professor of Plant Pathology and Mycology in South Africa, at Stellenbosch University. The field was just being established, not only in South Africa, but in many parts of the world, and its distinction from other disciplines was a matter of pride.

In this Commentary I use the Van der Bijl address as a 'lens of history' to reflect on the state and role of plant pathology today, and what might lie ahead as we approach the centenary of his presentation. In doing so I do not cover all elements of relevance to plant pathology currently, but focus on key issues he raised that influence plant disease development and management, the interdisciplinary and interconnected nature of the discipline, and the role it has in society. Despite the immense progress in knowledge and the power of the tools of the discipline since 1926, it is also necessary to reflect on the reasons why we need an International Year of Plant Health in 2020 (IYPH 2020) – not to celebrate success, but to highlight a growing crisis globally facing food security and environmental health due to the increasing pressure on plant health.

Despite the revolutions in plant pathology since 1926, pathogens and disease continue to outpace our efforts to manage them. The United Nations, in its communication about the IYPH 2020, claims that as much as 40% of global food production is lost due to pathogens, pests and weeds. In hindsight it is perhaps not unexpected news, as we understand clearly today that pathogens will evolve, and will evolve faster, under the strong selection pressure we place on them. In fact, the very measures we have developed over the past century to feed a growing world population, and that have delivered the Green Revolution, have also created an ideal scenario that speeds up the evolution and spread of virulent and resistant pathogens.[2] Clearly there are no silver bullets, irrespective of how extensive our new knowledge may be. There is a need to urgently reassess how we use what we have learned since 1926 and to apply it in a different manner if plant pathology is to optimally contribute to the health and well-being of our society, and our environment.

When reading the address by Van der Bijl in 1926 one is shocked to be reminded of how far our understanding of the biological cause of plant disease has developed since then. For example, at that time it was thought that most plant disease was caused by bacteria and fungi, except for the 'so-called mosaic diseases' for which no infective organism could be defined by the 'highest power of the microscope'. The term 'virus' was used for a potential 'ultra-microscopic' infective agent, but its nature remained obscure (as it did for human diseases such as the Spanish flu). In contrast, today the sequence of every nucleic acid building block of a pathogen can be determined as a matter of routine, we can consider the relevance of the 'pangenome' of a pathogen species, and accurately measure the changes in networks of molecular interactions at subcellular levels across minute time scales.[3,4]

Van der Bijl describes at some length the importance of the interaction between the host, pathogen and its environment in the development of disease – what has since become known as the 'Disease Triangle'. This concept has become deeply embedded in ecological and epidemiological concepts of disease development and has advanced to sophisticated mapping of the changes in these factors over time and space in order to direct management. An even more holistic picture is now emerging, sometimes called a (triangular) disease pyramid, that recognises the role of symbioses (in particular the extended genotype and phenotype of the host through its associated microbiome) in both animal and human disease development.[5,6] I would argue, however, that this picture is still incomplete, and that a fifth dimension – a square pyramid – that considers the influence of human social systems is also needed. This dimension is increasingly recognised for its importance in ecological systems that influence sustainability[7], and cannot be ignored in the management of plant health, because political, economic and cultural factors all directly interact or influence each of the other four factors that are accepted as drivers of plant disease development (Figure 1). Nowhere is this more evident than in two of the major drivers of global disease emergence, namely climate change and the rate of spread of invasive pathogens.

Van der Bijl notes that 'practically all countries have laws and regulations aimed at protecting them against the introduction of serious diseases from elsewhere, as well as against the spread of serious diseases…in the same country'. Unfortunately, these measures have proven woefully inadequate, with multiple waves of invasive pathogens causing devastation to crops and native ecosystems alike since then. In fact, nearly 100 years later, the emergence and spread of invasive pests and pathogens are increasing at a faster rate than ever before.[8] Ecological 'neighborhoods', referring to connected ecosystems, are nearly global for some pathogens. Rapid and repeated spread of pathogens or resistance across continents are now commonplace and create pools of genetic diversity and evolutionary potential in pathogens (a global evolutionary experiment) that is unprecedented. To make matters worse, climate change is increasingly placing unknown levels of stress on plant communities and opening new areas for infection for some plant pathogens (while possibly restricting others). While scientific advice to counter these negative trends is plentiful, their outcome is almost wholly determined by political and economic decisions. These social factors cannot be excluded from disease development, modelling and associated management decisions. What is certain is that we need to prepare to deal with a continued onslaught of emerging pathogens in agricultural and native systems for decades to come (even under the best scenarios).

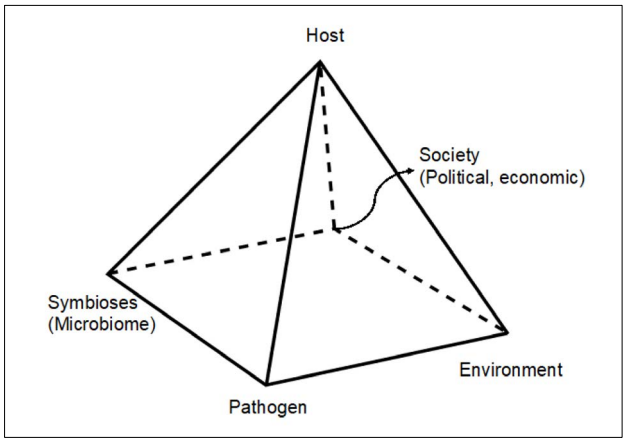

Figure 1: The Plant Disease Pyramid. Factors that influence disease development have been described in the classical 'Disease Triangle' concept. Recent work suggests that a fourth dimension, that of symbioses such as the microbiome are also critical to consider.[5] Here I argue for a fifth dimension, namely the societal factors (cultural, political and economic) that have profound impact on disease development and outcomes on scales from the local to the global. Social-ecological interdependencies are increasingly well defined for sustainable development[7] and would provide a useful starting point to integrate these concepts into disease development models and management forecasts.

Capacity is required to face the enormity of the current global plant health crisis and to implement an integrated systems approach to plant health. One must thus be alarmed by a common reflection in recent years in South Africa in the agricultural sciences, including plant pathology, over the concern for the 'health' of the discipline, mergers and the disappearance of historical departments or faculties, an 'aging' cohort of leading researchers, lower student numbers and reduced financial support. In preparing this article, it was interesting to read the expression of almost identical concerns in reflections from the early 1900s, 1950s, 1970s and more recently, from across the world. Yet breakthroughs in the field now, as in the past, continue to come from universities and research institutes without formalised 'Plant Pathology' units. The problem thus does not seem external, i.e. how university structures or student choices influence the discipline, but how those who understand its importance, and carry the current responsibility and knowledge in the discipline, are able to provide leadership and innovation in developing structures that respond to the current realities. From that perspective I am optimistic when I see many exceptional and innovative young leaders in the field today. As Van der Bijl had to do, those in leadership positions must focus on creating opportunities for the generations to come, as opposed to only for themselves.

The challenge of capacity was even harder in Van der Bijl's time, as he was the only formal plant pathologist appointed at professorial level. The challenge was undoubtedly made worse by the fact that the teaching of plant pathology in 1926 was only available for white 'men ... to be better farmers …, government agents …, teachers … and research workers' (which is a small fraction of the population). There is fortunately a much broader base of capacity in South Africa today, and plant pathology is no longer only seen as merely a 'phase of botany', as Van der Bijl described it. The country has a well-established South African Society for Plant Pathology, and the topic is taught in many universities in South Africa, as it is globally. Yet, in industry and in government, one still often hears of frustration about capacity constraints. Unfortunately, some consequences of a sexist and racist history are also not yet completely eradicated, as in many other parts of the world, leaving much of the true potential talent in the country untapped for the field. As we look to the future, we need to use all the insight and courage we have to tackle remaining hurdles in this regard. Targeted efforts are needed to recruit South Africa's brightest stars, from the youngest ages to undergraduate courses, by exposure to the critical role and exciting options that the field offers. The interdisciplinary nature of plant pathology offers opportunity to target students from a very broad background of original training to enter the field and work as part of interdisciplinary teams.

Throughout his address Van der Bijl refers to the farming community, research community and government as an integrated network dealing with plant diseases – demonstrating that a transdisciplinary, team- and system-based approach is part of the foundation of plant pathology. It is a pity that this team-based foundation of the discipline has given way to a competition driven, individualistic development of the 'PI-lead Lab' approach, and that we have often (as in many fields of science) celebrated the lone figure (often referred to as the 'father') of certain fields or breakthroughs, as opposed to the teams inevitably behind them. Van der Bijl refers to the first university in the world to establish a Department of Plant Pathology, the University of California, Berkeley, where Ralph E. Smith at the time fostered an approach of the 'department as a family working together towards a common end, solving problems that baffle and discourage people…'.[9] A team-based approach not only gives the opportunity to develop a more interdisciplinary scope, but also one that can address complex, real-world problems in a more effective manner, aim for higher quality outputs and impact, and attract a broader range of talent. It is my view that we should be celebrating the success and impact of teams, both as an accurate reflection of actual input and for the sake of the health of the attractiveness of the discipline. It is something to aim for in the years ahead.

The control measures that Van der Bijl was excited about reflect very crude, and sometimes blind, application of chemicals such as the Bordeaux mixture (lime and copper sulfate mixture) at the time. While an increasing understanding of the epidemiology of diseases was starting to direct more sensible use of chemicals, even in 1926, we unfortunately look back on a history since then of very injudicious use of chemicals, with a focus on immediate increases in productivity that ignore longer-term impacts on sustainability. There have been very substantial negative impacts on the environment, and the emergence of resistance to many chemicals in pathogens that limit choices for future use. There is a very real possibility today to apply these chemistries with precision in time and space, and in combinations with various others tools, in ways that minimise waste, optimise impact and consider plant health as part of a holistic system. In addition, the diversification of crops (for both nutritional and disease management reasons), unlocking of genetic sources of resistance in wild populations through genetic engineering, and the increasing use of biologicals for management, amongst other options, hold potential to contribute even more to disease control in future. We need to learn from the past that none of these will be a silver bullet or provide permanent solutions. Rather, a continuously adaptive and resilient system that can buffer against shocks such as pandemics, and that can continue to evolve as various elements of the 'five dimensions' of disease development and management change (Figure 1), should be the aim of plant pathologists, in collaboration with other fields and sectors of society.

One of the most neglected areas of plant pathology in South Africa is the systematic capture of information about disease outbreaks and impact. Van der Bijl expresses the hope that the newly established 'divisions of Agricultural Economics and Agricultural Extension' will gather more systematic knowledge on the impact of plant disease. Sadly, this has not happened and data on the impact of disease on yield, its geographic variation, changes over time and other vital information are not available for most plant diseases in a systematic manner in South Africa today. Information that is available internationally through bodies such as the FAO and CABI is often lacking in detail, especially from Africa. International efforts have recently been launched to attempt to address some of these knowledge gaps and it is important that plant pathologists in South Africa and Africa participate in these to unlock hidden and collect missing information (see for example the project on the Global Burden of Crop Loss; www.croploss.org). It is even more urgent than it was in 1926, given increasing pressure and resource constraints, that South Africa develops strong national pest and disease information systems for its local planning and forecast.

While the description of a squared disease pyramid (Figure 1) as a fundamental basis for plant health management might be relatively new as a concept, the importance of every one of the five dimensions I mentioned was described and discussed in Van der Bijl's address in 1926. We have clearly come a long way since then in our ability to characterise plant disease at the finest scales, and have enormously powerful tools to target and manage these diseases. The same can be said for human disease. Yet, this article is being written in a time when the world is facing the pandemic caused by the SARS-CoV-2 virus. More knowledge and more powerful tools do not necessarily translate into better management over time. It is essential in the years that lie ahead that plant pathologists consider how to deploy the tools at their disposal in ways that reduce the opportunity for evolution and spread of pathogens. As with human disease we have a long way to go to increase connection, representation, reach and impact of the powerful tools at our disposal to secure the nutrition and fibre the world needs, as well as our planetary health. A well-functioning and structured network of collaboration amongst government departments, research institutions, universities and industries is even more necessary today than it was in 1926 to manage national plant health, and should be the primary concern for plant pathologists today. Knowledge only becomes powerful when it is used.

The collision of the COVID-19 pandemic and the IYPH 2020 has wreaked havoc on a year of meetings and workshops aimed at dealing with the global crisis facing plant health management. This collision, however, also offers an opportunity to capitalise on the greater societal understanding of the threat of globally spreading diseases, and the need to be prepared and to invest in the resilience of health management sciences. It demonstrates that the capacity to respond to such a crisis is not a tap you can turn on, but rather a reservoir one needs to build to feed the tap when the crisis hits. It would be a mistake, however, to think that the message will come across automatically. As an example, there have been at least four global flu pandemics since the Spanish flu of 1918, and yet society and its political machinery seemed to quickly forget their warnings. Keeping society informed, and policies implemented, fighting for resources for training and research to reduce the devastation that invasive plant pathogens can cause to our livelihoods, our food safety and our environment, will require an ongoing effort and dedicated leadership.

References

1. Van der Bijl PA. Landmarks in the development of the science of plant pathology and of disease control. S Afr J Sci. 1926;23:42–60.
2. McDonald BA, Stukenbrock EH. Rapid emergence of pathogens in agro-ecosystems: Global threats to agricultural sustainability and food security. Philos Trans R Soc B. 2016;371(1709), Art. #20160026. https://doi.org/10.1098/rstb.2016.0026
3. McFaline-Figueroa JL, Trapnell C, Cuperus JT. The promise of single-cell genomics in plants. Curr Opin Plant Biol. 2020;54:114–121. https://doi.org/10.1016/j.pbi.2020.04.002
4. Steinberg G, Schuster M, Gurr SJ, Schrader TA, Schrader M, Wood M, et al. A lipophilic cation protects crops against fungal pathogens by multiple modes of action. Nat Commun. 2020;11:1608. https://doi.org/10.1038/s41467-020-14949-y
5. Brader G, Compant S, Vescio K, Mitter B, Trognitz F, Ma L-J, et al. Ecology and genomic insights into plant-pathogenic and plant-nonpathogenic endophytes. Annu Rev Phytopathol. 2017;55:61–83. https://doi.org/10.1146/annurev-phyto-080516-035641
6. Bernardo-Cravo AP, Schmeller DS, Chatzinotas A, Vredenburg VT, Loyau A. Environmental factors and host microbiomes shape host–pathogen dynamics. Trends Parasitol. 2020;36:616–633. https://doi.org/10.1016/j.pt.2020.04.010
7. Reyers B, Selig ER. Global targets that reveal the social–ecological interdependencies of sustainable development. Nat Ecol Evol. 2020;4:1011–1019. https://doi.org/10.1038/s41559-020-1230-6
8. Wingfield MJ. Bröckerhoff EG, Wingfield BD, Slippers B. Planted forest health: The need for a global strategy. Science. 2015;349:832–836. https://doi.org/10.1126/science.aac6674
9. Snyder WC. Plant pathology today. Annu Rev Phytopathol. 1971;9:1–7. https://doi.org/10.1146/annurev.py.09.090171.000245