Where Will the Next Norman Borlaug Come From? A U.S. Perspective of Plant Pathology Education and Research

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Abstract

Martyn R.D. (2009): **Where will the next Norman Borlaug come from? A U.S. perspective of plant pathology education and research**. Plant Protect Sci., **45**: 125–139.

Plant diseases can be traced back almost as far as recorded history. Numerous ancient writings describe plagues and blasts destroying crops and modern civilization still faces many plant disease challenges. Plant pathology has its roots in botany and notable scientists such as Tillet, Prevost, and deBary already had concluded microscopic organisms could cause plant diseases before Robert Koch established the rules of proof of pathogenicity with sheep anthrax. Plant pathologists can be credited with helping improve crop yields and food production throughout the world. However, at a time when there are increasing challenges to crop production, some that potentially may increase the severity or distribution of plant diseases, the training of future plant pathologists appears to be declining, at least in the United States. The ability of the U.S. Land Grant University (USLGU) system to attract and train future generations of plant pathologists may be at risk. Recent data from university plant pathology departments collected by The American Phytopathological Society (APS) documents a decline in the number of students completing advanced degrees in plant pathology, departments with fewer faculty with a diverse expertise in applied plant pathology, fewer stand-alone, single discipline departments of plant pathology, a reduced ability of many departments to offer specific curricular aspects of plant pathology, and a demographic profile that casts an ominous prediction for an unusually large number of faculty retirements over the next decade. The impact of these factors could be a shortage of highly skilled, applied plant pathologists in the U.S. in coming years. The affect also may be felt globally as fewer international students may receive predoctoral and post-doctoral training in plant pathology in the U.S. as faculty retire and are not replaced. On the other hand, this likely will create greater opportunities for universities around the world to take leadership in many aspects of plant pathology education. While a decline in students and young faculty trained in applied and field-level specialties of plant pathology (mycology, bacteriology, plant nematology, forest pathology, epidemiology, etc.) is occurring, those trained in the cellular and molecular host-pathogen interactions specialties appear to be increasing. Many plant pathology faculty hired at USLGUs in the last decade are trained in molecular biology and received their Ph.D. degree in a field other than plant pathology. They are now applying those skills to research numerous aspects of host-pathogen interactions of model pathosystems. A shift to a greater research emphasis on molecular host-pathogen interactions over the last decade is evidenced by the number of research articles published in the three APS journals; Plant Disease, Phytopathology and Molecular Plant-Microbe Interactions (MPMI). From 1985 to 2007, there has been a decline in the number of articles published in Plant Disease (–29%) and Phytopathology (-36%) and a steady increase in those published in MPMI since its inception in 1990 (+111%). With new research tools come new research questions. The tools of molecular biology have allowed us to look deeper into questions than ever before and provided us with a perspective not before seen. As we dissect and decode the genomes of the world's most notorious plant pathogens we get closer and closer to alleviating the global losses and human suffering caused by plant diseases. New "designer crops" with

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engineered traits for drought and cold tolerance, pest resistance, increased levels of micronutrients, healthier oils such as omega fatty acids, and plant-derived pharmaceuticals are all on the horizon. Research in the future likely will focus on new problems, traditionally seen as outside the discipline of plant pathology. The impact of climate change on plant diseases will be significant. As many parts of the world become warmer and drier some plant diseases likely will increase in severity. Pathogens are likely to migrate and survive in more northern latitudes greatly expanding their range and diseases exacerbated by abiotic stresses such as drought and salinity will increase. Plant pathology will continue to evolve as a multidisciplinary science. These changes will open up many new research opportunities. Plant pathology will play a bigger role in global food security. Research into the molecular and cellular interactions of symbiotic and endophytic organisms will help provide answers to food-borne illnesses caused by *E. coli* and *Salmonella* and how these and other human pathogens become established in plants in the field. Plant pathologists will team up with biomedical and aeronautical engineers, nanotechnologists, and computer scientists to develop microsensory technology to detect the introduction and spread of pathogens for biosecurity, diagnostics and epidemiological modeling purposes. Traditional areas of plant disease management and the use of biologicals for disease control also will benefit from a better understanding of the molecular and cellular processes and the similarity of virulence mechanisms and pathogen effectors between plant, insect, and vertebrate pathogens likely will bring new insights into human diseases. And last, but not least, there likely will be a resurgence in plant disease management and epidemiological research as the world's dependence on biofuels increases and results in new diseases on intensively cultivated plant species used for biomass production.

Keywords: the American Phytopathological Society – APS; U.S. Land Grant University; plant pathology education; applied plant patology; future of plant pathology

The damaging effects of plant diseases have been evident since the beginnings of recorded modern civilization. Ancient writings in the Old Testament of the Bible (approx. 750 B.C.) describe blasts and blights of cereal crops such as wheat and barley and the Greek philosophers Democritus (470 B.C.) and Theophrastus (370 B.C.) wrote of blasts, blights, rusts and mildews. Rust was such a serious problem on cereals in the fourth century B.C. that the Romans had a separate god, Robigus, the god of rust, to whom they sacrificed red animals (dogs and foxes) in an attempt to appease him so he would not send the rust to destroy their crops. Plant pathology had its beginnings in botany and notable people such as Mathieu Tillet (1755), Benedict Prevost (1807) and Anton deBary (1861–1863) had experimental evidence that fungi could cause plant diseases years before Louis Pasteur (1864–1865) had proven the germ theory of disease and Robert Koch (1876) established the rules of proof of pathogenicity (Koch's postulates) with sheep anthrax.

History is replete with stories of human suffering inflicted by plant diseases. Potato late blight, ergot, wheat rust, and wheat smut are but a few plant diseases that have gained notoriety, but many others also fill the history pages. Although it has been over 150 years since the modern era of plant pathology began, plant diseases still inflict suffering on untold millions of people worldwide causing an estimated annual yield loss of 14% globally with an estimated economic loss of $220 billion U.S. dollars (Agrios 2005). The importance of plant pathology in human civilization cannot be understated. World population continues to grow, and will likely reach an estimated 9 billion by 2040. Starvation and malnutrition are still rampant in many parts of the world. The Food and Agricultural Organization (FAO) estimates that the number of undernourished people in the world today is 842 million (Raney 2004). Another 3 billion suffer from the lingering and debilitating effects of micronutrient deficiencies. While the total number of undernourished people in some parts of the world is decreasing, the situation is either no better or getting worse in Latin America and Sub-Saharan Africa, where more than one-third of the population is undernourished. In 2003, 38 countries faced a serious food shortage emergency, as defined by the FAO (Raney 2004).

Much of the world's arable cropland is already intensively cultivated, leaving little good, produc-

tive land for increased cultivation. Increased food demand by a growing world population, a decrease in the availability of fresh water, negative impacts of climate change on crop production (Parry *et al*. 2007), and increases in exotic and invasive plant pests and diseases will strain and challenge agriculture around the world. Our ability to feed, clothe and shelter the world's population is contingent upon a healthy, viable, productive and sustainable global agricultural system. Food security is one of the world's most critical issues (Strange & Scott 2005; Borlaug 2009). When agriculture fails – humanity fails (Martyn 2008).

While modern plant pathology education and research had its beginnings in Europe, the United States has played a major role in the advancement of the science and practice of plant pathology. The many scientific advances, not only in plant pathology, but also across all of the agricultural and engineering disciplines, can be attributed in large part to the establishment of the U.S. Land Grant University (USLGU) system and the State Agricultural Experiment Stations. The Morrill Act of 1862, passed by the U.S. Congress during Abraham Lincoln's presidency, granted federal lands to states for the purpose of building educational institutions that would focus on and emphasize teaching of the agricultural, science and engineering disciplines. This concept was modeled after The Agricultural College of the State of Michigan, chartered in 1855 (now Michigan State University) and the Farmers' High School of Pennsylvania, also chartered in 1855 (now Pennsylvania State University). The first newly created land-grant university under the Morrill Act was Kansas State University, established in 1863. Today, there are over 70 land-grant universities and colleges in the U.S and its territories. The mission of the land-grant universities was substantially expanded with the passage of the Hatch Act of 1887 that also provided federal lands to states to establish agricultural experiment stations and which would become the research arm of the land-grant universities. The outreach mission of the land-grant universities was realised with the passage of the Smith-Lever Act of 1914, establishing the Cooperative Extension Service. Thus, the three missions of the land grant system, teaching, research and extension, were brought together under one university. The U.S. Land-Grant University System has become a model for education, research and outreach highly regarded around the world.

At a time when there are increasing challenges to crop production, many of which potentially increase the distribution or severity of plant diseases globally, the training of future plant pathologists skilled in techniques of applied plant pathology, disease diagnosis and management appears to be declining, at least in the United States. Almost 40 years ago, Dr. Norman Borlaug received the Nobel Prize for Peace for his efforts in breeding stem rust resistance in wheat. Dr. Borlaug received his M.S. and Ph.D. degrees in plant pathology from the University of Minnesota and his research lead the way for the Green Revolution and has been credited with saving the lives of a billion people. Today, a new virulent race *of Puccinia graminis* f.sp. *tritici* (Ug99 / TTKS) threatens wheat production in the Middle East and is of great concern to India, Europe and North America (MacKenzie 2007). Where will the next Norman Borlaug come from? Who will train the next generation of plant pathologists skilled in the science and techniques of disease resistance breeding, disease diagnostics, epidemiology and disease management?

The Vision of the American Phytopathological Society

The American Phytopathological Society (APS) has been concerned about the future of the profession for a number of years. As early as 1993 (and probably before that), an APS *ad hoc* committee was established to identify priorities for plant pathology in the 21st century. This committee, 'Plant Pathology Beyond 2000', was chaired by APS Past-President Randy Rowe and identified a number of goals that would have to be attained to keep plant pathology relevant in the future. Among these was renewing the attractiveness of plant pathology as a career objective for students. Just like industry needs a supply of raw materials to make their products, universities need a supply of graduate students to make the next generation of scientists. If a company's supply of raw materials is disrupted, so too is its products. If university faculty can not recruit graduate students, then the global inventory of scientists is disrupted. In order to recruit quality graduate students, universities need to have modern, relevant programs and curricula. This is not only critical for today's students but tomorrow's also. Tomorrow's discoveries will be made by today's students.

For many years, the demand for graduate assistantships in plant pathology at USLGUs far exceeded their availability. Many plant pathology departments had their pick of highly qualified applicants and many more applicants were turned away each year. Today, however, most plant pathology departments are struggling to maintain sufficient numbers of graduate students, and some, are losing them altogether. While competition for the best students has always been keen, today it is more difficult than ever to recruit top students. Even the most storied U.S. plant pathology departments have experienced a decline in graduate student numbers over the last decade or more.

A second APS *ad hoc* committee was established in 2000 primarily to expand on the information generated by the first committee and, secondly, to create a 'vision of what plant pathology ideally would be in the 21st century'. This committee, chaired by Joyce Loper, divided their vision statements into two types: some representing predictions of what likely is to come, while others represented goals that the community of plant pathologists should work towards (areas of endeavor) to help bring to fruition (APS ad hoc committee report, 2000). Of particular note is a section of the committee's report on 'the education of plant pathologists'. Two of their vision goal statements are particularly germane to the present discussion: "… concepts of plant pathology will become essential components of the core courses of undergraduate education" and "Plant pathology will be visible and attractive to undergraduate students, resulting in a large pool of applicants to graduate programs". These two goals are vital to creating the pipeline of future graduate students; however, unfortunately, neither appeared to have come true yet. In spite of this, these vision goals remain a high priority for plant pathology and APS.

Beginning approximately in the mid-1980s and early 1990s, there was a trend among USLGUs to downsize their faculty, initiated largely by state budget cuts. This occurred primarily by the elimination of positions as faculty retired or left their positions for other reasons. Over time, vacated, unfilled faculty positions resulted in significant reductions in staff in many departments and colleges. A common perception was that over time, fewer faculty would result in fewer graduate students and fewer graduate students would result in fewer course offerings and, thus, fewer postgraduates. Fewer faculty and postgraduates would result in fewer publications and fewer grants. As departments became smaller, and presumably weaker, they might lose their critical mass and relevance and become ripe for elimination or merger with other small departments by upper-level university administrators. Thus, it could be the beginning of a downward spiral, destined to destroy the very fabric of plant pathology. Has this happened and, if so, has it destroyed the very fabric of plant pathology?

To address this question and others, two additional *ad hoc* committees were established by APS in 2006. The first committee was the APS Ad Hoc Committee on the Present Status and Future of the Profession of Plant Pathology and chaired by David Gadoury of Cornell University. This committee initiated a census study of the current status of plant pathology at the USLGUs and assessed such metrics as the disciplinary balance within plant pathology departments, institutional erosion, research funding and age demographics in the plant pathology community. Their report to APS Council in 2008 has been published as a feature article in Plant Disease (Gadoury *et al*. 2009).

The second committee was the APS Ad Hoc Committee on the Future Education of Plant Pathologists and was chaired by APS Past-President James MacDonald of the University of California, Davis. This committee was charged with assessing the current status of graduate education in plant pathology at the USLGUs and their perceptions about the future. They focused much of their effort in gathering data on the types of graduate courses offered by departments, how students and program chairs perceived the quality of the courses and how students and potential employers perceived the job market. This committee's report was also published as a feature article in Plant Disease (MacDonald *et al*. 2009) and also is available as a webcast on APSnet <http://www.apsnet.org./webcasts/initiatives.asp>.

What follows in this present article is my summary and interpretation of some of the data and information largely collected and synthesized by these two APS *ad hoc* committees over the past two years. I am grateful to the committees for sharing their data with me and full credit is extended to them. In addition, in 2008, I conducted an informal survey of plant pathology departments at the USLGUs to determine if, in fact, there had been any institutional erosion of the plant pathology name.

Faculty demographics at U.S. Land Grant Universities

Perhaps one of the most obvious questions is how has plant pathology faculty hires changed over time. Historical data on the number of faculty hires in plant pathology at USLGUs is shown in Figure 1. During the decades 1966–1975 and 1976–1985, almost 50 faculty per year were hired in plant pathology departments at USLGUs.

The ensuing decade of 1986–1995 saw a 50% + drop in the number of faculty hires. This decline continued through the first half of the following decade, but did show a small increase in the last half of the decade (2001–2005). The 15-year hiring decline from the mid 1980s to 2000 mirrors the period of significant budget reductions at most USLGUs. During this same time period, the number of plant pathology faculty declined at most USLGUs. This correlates with the first major retirement cohort, as faculty hired during the 1950s and early 1960s retired and many of their positions were not replaced. The median age of the current university plant pathology faculty is 52 years and a second cohort of faculty are entering the retirement phase now and their number is expected to increase to approximately 50% of the population within 12 years (Gadoury *et al*. 2009). The demographic trends seen among USLGU faculty are mirrored in the population of plant pathologists in the USDA Agricultural Research Service (ARS).

Among the 172 plant pathologists currently employed by ARS, from 30–34% will be eligible to retire in 2009 (2006–2010 ARS Workforce Plan; cited in Gadoury *et al*. 2009).

While it is not possible to get an accurate historical account of the total number of plant pathology faculty at all USLGUs during the 1960s and 1970s, it is safe to say that it is considerably less now. A 2007 census of plant pathology faculty of 58 departments conducted by the Gadoury committee places the current number at 673. These are self-described plant pathologists and are members of plant pathology departments or multidisciplinary departments of which plant pathology is one of the disciplines. The combined total number of faculty in these 58 departments is 1455; thus, plant pathology accounts for less than one half (46%). Three departments no longer have any plant pathology faculty and 18 (31%) have fewer than five. An almost equal number (19) make up the largest departments with more than 15 plant pathology faculty, while seven departments have 25 or more. The Gadoury committee was able to obtain historical faculty data for eight of the largest U.S. plant pathology departments (Figure 2).

Collectively, there has been a steady decline in the number of plant pathology faculty at eight major departments from a total of 202 in 1987 to 151 in 2007, a decrease of 25%. Every department experienced a decline during this period except one (department H), which had a slight increase during the last couple of years.

As mentioned earlier, as the number of faculty declined, there was a trend among some USLGUs to merge the now-smaller, single discipline departments with other small, discipline-related departments forming larger, multidisciplinary departments. Disciplines often merged together include some combination of plant pathology, weed science, agronomy, entomology, biology, etc. These mergers resulted in fairly large (40 + faculty) departments with names such as plant sciences, plant, soil and insect science, plant, animal and soil science, entomology, soils and plant sciences,

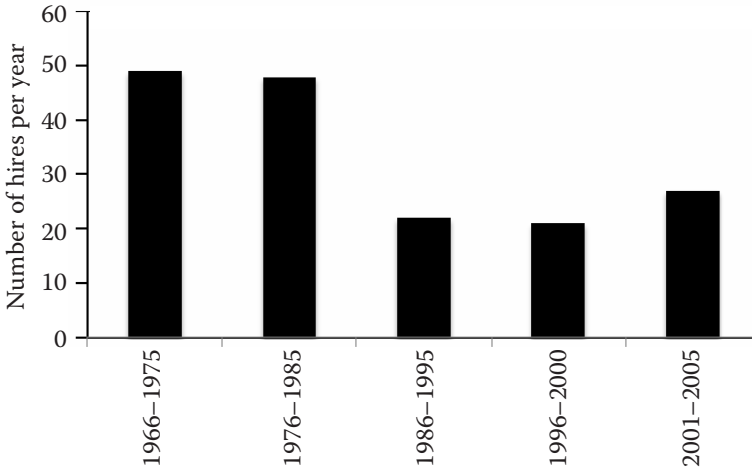

Figure 1. Annualised number of hires/year of newly graduated PhDs in plant pathology at 4-year institutions (source: National Science Foundation Survey of Earned Doctorates; Gadoury *et al*. 2009)

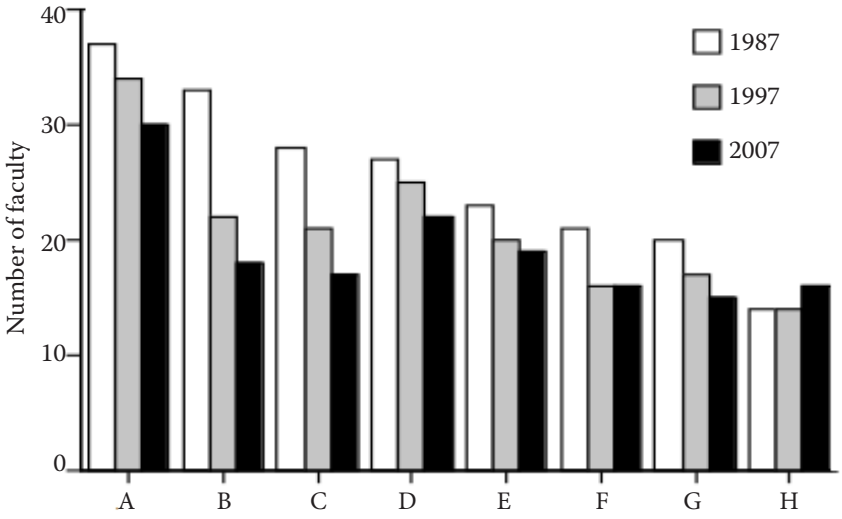

Figure 2. Number of plant pathology faculty at eight USLGUs from 1987 to 2007 (modified from Gadoury *et al*. 2009)

A–H: Letters denote specific departments of plant pathology at eight USLGUs. The university names have been purposefully reported anonymously

and others. In some cases plant pathology was lost completely from the department name, while in other cases, it was incorporated into a longer department name such as entomology, plant pathology and weeds, plant pathology and crop physiology, etc. The resulting loss in name recognition and visibility of these combined departments is a concern of many plant pathologists. The perception is if plant pathology is not visible and identifiable in the department name then students may not know plant pathology exists. If we are not identified by discipline in university catalogues, how will they find us? This fear is tempered somewhat by survey data collected by the MacDonald ad hoc committee (MacDonald *et al*. 2009). Current graduate students across the country were asked to identify the primary factors that attracted them to plant pathology. The top three, mentioned by more than 50% of all respondents were: (1) an undergraduate work experience in plant pathology; (2) a close friend or advisor who was a plant pathologist; and (3) taking an undergraduate class in plant pathology. Thus, it may not be name recognition per se as much as a positive experience exposing them to plant pathology for the first time. The controversy, however, continues and the question remains "has there been a decrease in single-discipline, stand-alone departments of plant pathology in the U.S. and what, if any effect, has it had on graduate students?"

A survey by this author (Martyn 2008, unpublished) of 53 departments in the U.S. with a history of offering graduate degrees in plant pathology was conducted in 2008 to ascertain two basic pieces of information. First, what was the name of your department in the mid 1970s (approximately 1975) and what is its name now? And, second, did you offer a graduate degree (M.S. or Ph.D.) in plant pathology in 1975 and do you offer one now? The data are quite revealing (Figure 3). In the mid 1970s, there were 30 stand-alone departments of plant pathology (e.g., plant pathology department or department of plant pathology) among the 53 USLGUs and another 17 that had plant pathology in the department name (e.g., department of botany and plant pathology). Only six departments did not include 'plant pathology' in their name. Thus, in the mid 1970s, 47 out of 53 departments (89%) were identified in some way as 'plant pathology' (Figure 3A). In 2008, only 16 stand-alone plant pathology departments remained, a decrease of 14 (–47%) and 40% of the departments (21) no longer were identified by plant pathology in the name (Figure 3B).

Graduate student education

Has the decline in faculty and/or departmental name changes affected graduate student numbers? It is not possible to say with certainty, but the number of students receiving their Ph.D. degree in plant pathology from USLGUs provides some insight. The U.S. National Science Foundation (NSF) maintains a record of Ph.D. degrees awarded each year in the United States in a number of disciplines. The number of earned doctorates in plant pathology for the last 45 years is shown in Figure 4. For 3½ decades (1966–2000) there was a steady rate of about 100 new plant pathology

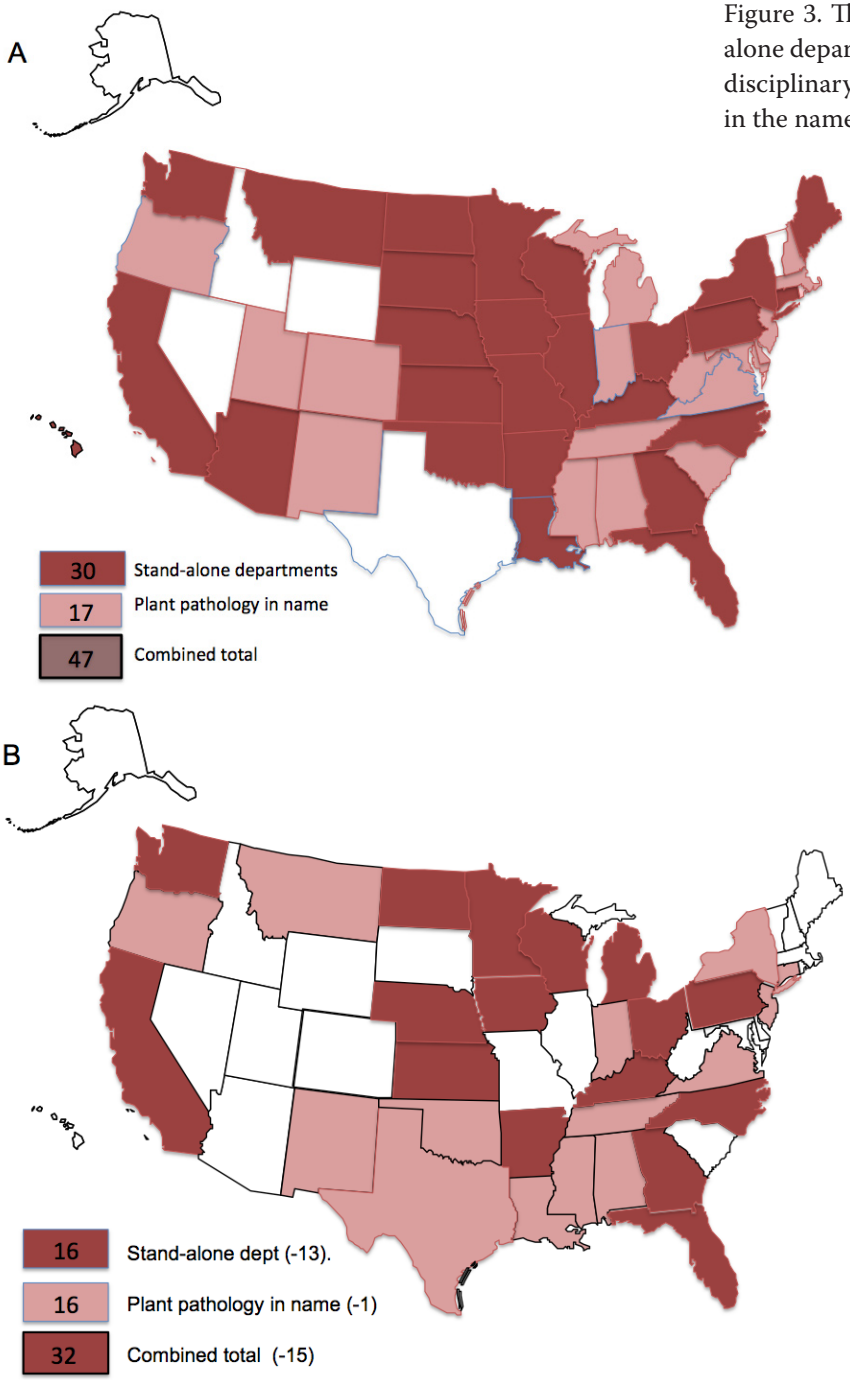

Figure 3. The number of USLGUs with stand-alone departments of plant pathology or multi-disciplinary departments with plant pathology in the name: A = mid 1970s. B = 2008

Ph.D.s every year, but for the first 5 years of 2000 (2001–2005) the number dropped to 84 per year, a decline of 15%. It is not possible to conclude that any decline in degrees awarded is a result of department mergers and name changes, but it is likely the result of fewer plant pathology faculty training new students at the USLGUs.

Some institutional erosion of plant pathology graduate programs appears to be occurring. In 2008, at least 10 of the 53 departments surveyed no longer offered a graduate degree in plant pathology and many more offered only an 'area of specialization' in plant pathology (Martyn unpublished). The decline and near-disappearance of plant pathology also was documented by the Gadoury committee (Gadoury *et al.* 2009) at six New England Land Grant universities. Since 1985, four universities no longer offer a Ph.D. in plant pathology and the remaining two offer a Ph.D. in an allied discipline with a focus on plant pathology. In 1985, all six universities offered a variety of undergraduate and graduate courses in

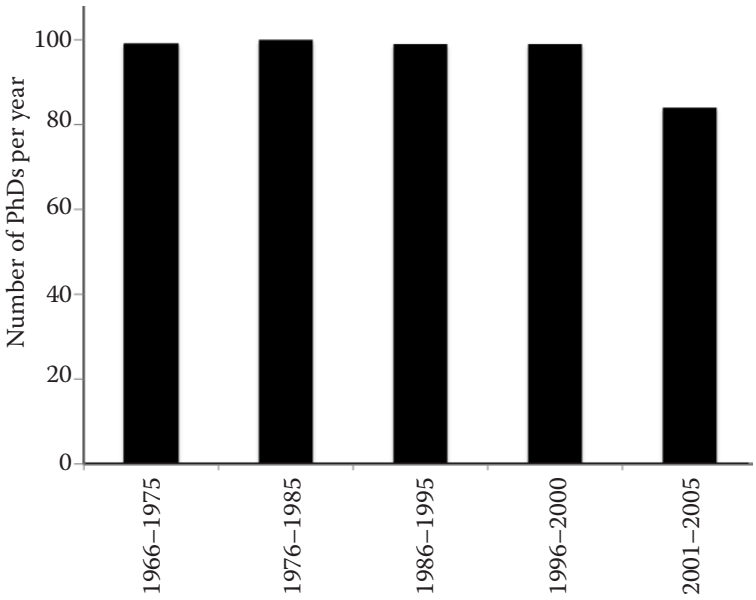

Figure 4. Annualised number of Ph.D. degrees in plant pathology awarded for 10-year intervals from 1966–2005 (adapted from Gadoury *et al*. 2009; source: National Science Foundation Survey of Earned Doctorates)

plant pathology and the aggregate annual enrollment in undergraduate plant pathology courses was 210. None of these universities today have annual course offerings in plant pathology and none identify the discipline of plant pathology in the department name.

Cases like this do not bode well for the training of future generations of plant pathologists. To assess the general academic health of plant pathology at the USLGUs, the MacDonald committee (MacDonald *et al*. 2008) conducted extensive surveys of current graduate students and graduate program chairs for their opinions of, among other things, the types of courses offered at their institutions, their ability to attract and recruit graduate students and their overall feeling for the future of various aspects of their program. A detailed account of the MacDonald committee's report may be viewed at http://www.apsnet.org/webcasts/initiatives.asp. I summarize only a few major points here. One of the survey questions asked was '*what are the required courses at your institution for a graduate degree in plant pathology?*' (Figure 5). Percentage of graduate programs at USLGUs requiring specific courses for a Ph.D. degree in plant pathology (adapted from MacDonald *et al*. 2008) might be expected, answers to this question were highly variable across all departments, however, there are some surprising results. First, at more than 70% of the departments surveyed, only two courses were required (core courses) for a graduate degree in plant pathology – a general plant pathology class and an advanced seminar. Secondly, the four pathogen-specific courses that traditionally have been the backbone of plant pathology programs, e.g., mycology, bacteriology, virology, and nematology, were required by fewer than 40% of the departments. Similarly, epidemiology was required by only 20% of the departments. Thus, taken as a whole, only 20% of the departments surveyed currently require the traditional courses in plant pathology for an advanced degree. None of the departments surveyed required a class in forest pathology. This does not necessarily imply that students do not take these courses during their program as both mycology and virology are '*strongly encouraged*' at slightly over 50% of the institutions and bacteriology, and epidemiology are '*strongly encouraged*' at about 40% of the departments. In a few cases, however, some traditional plant pathology courses e.g., forest pathology, epidemiology, virology, bacteriology, and nematology are no longer offered at all or are available at fewer than 25% of the departments (Figure 6).

It is difficult to compare these data to historical data but I think it is safe to say much has changed in 35 years. In the mid 1970s, many, if not most, departments had a required core of courses covering the basic pathogen-specific groups, epidemiology, disease management and perhaps disease diagnosis that were required of all graduate students and, clearly, this is not the case for most departments today. How does this potentially impact the future training of applied plant pathologists? One additional data set from the MacDonald committee sheds some light on the situation. Graduate

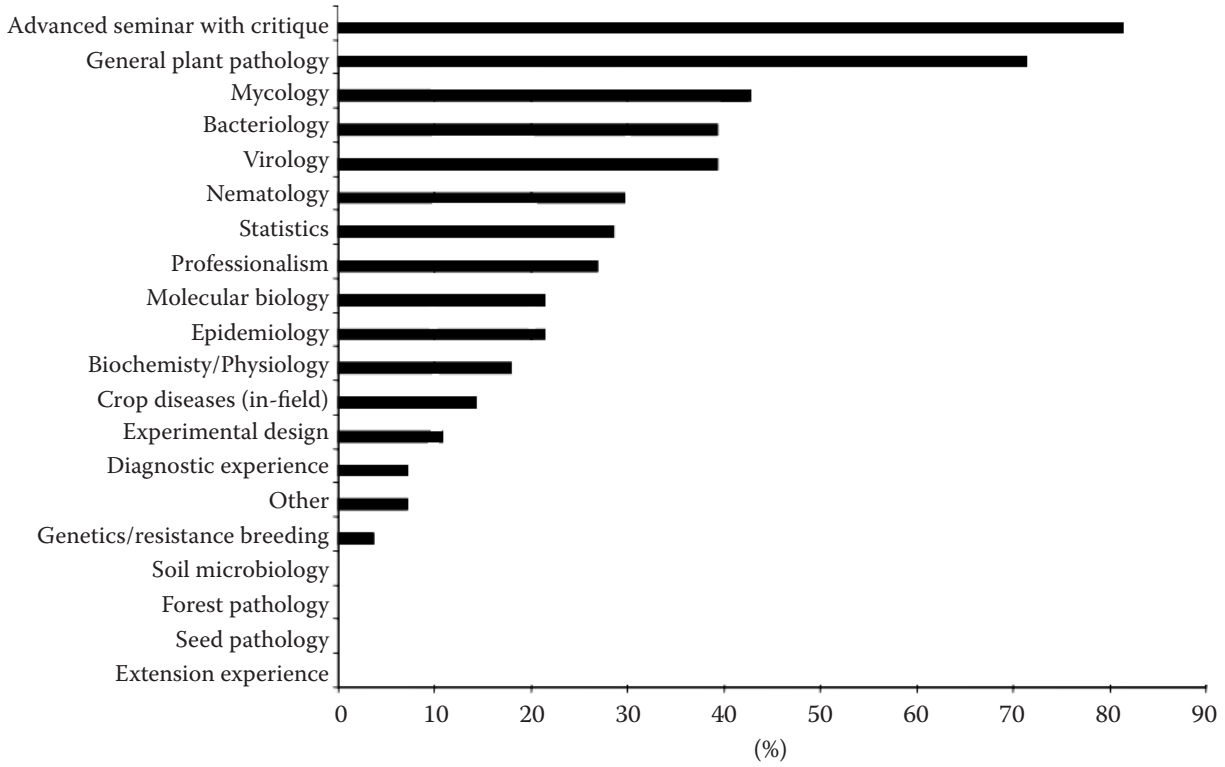

Figure 5. Percentage of graduate programs at USLGUs requiring specific courses for a Ph.D. degree in plant pathology (adapted from MacDonald *et al*. 2009)

program heads were asked to rate their concern as to the department's ability to sustain specific sub-disciplines of plant pathology over the next 10 years. Ratings were assigned on a 0–4 scale where 0 was 'not concerned' and 4 was 'highly concerned' about the department's ability to sustain coverage in the various sub-disciplines (Figure 7).

These data show that over 50% of the program heads were either 'fairly concerned' (#3 rating) or 'highly concerned' (#4 rating) about their department's ability to maintain adequate coverage in the traditional areas of plant pathology, including epidemiology, nematology, bacteriology, disease diagnostics, virology, biochemistry/physiology, mycology and breeding for resistance. This concern likely stems from many departments having fewer faculty with specific disease expertise, fewer graduate students interested in applied and field-level plant pathology, and a shrinking federal grants program supporting applied plant pathology research. If these fears are realized in the next decade, who will train the next Norman Borlaug and where will he/she come from?

When it comes to making products, universities are not all that different from industry. Companies make things and they require a skilled labor force and a sustainable supply of raw materials. And they need a viable market in which to sell their products. Universities also make things – they educate and train young scientists. To do this universities need the same things private industry needs: (1) a skilled labor force (faculty), (2) a sustainable supply of raw materials (graduate students), and (3) a viable market for their products (a good professional jobs market). A concern among many plant pathology faculty is that there is a declining number of new graduate students interested in the applied areas of plant pathology as a career choice. Many departments have experienced significant declines in the number of student applications in fields such as forest pathology, field crop pathology, epidemiology, extension plant pathology, etc. At the same time they have seen an explosion of students interested in the molecular and cellular aspects of our discipline. Survey data from the MacDonald committee (2008) tends to validate this. Of the departments surveyed, less than 40% thought they were above average in their ability to recruit top domestic Ph.D. applicants into their programs and 25% considered themselves to be below average. The reasons cited were lack of sufficient faculty in traditional areas of plant pathology (60%) and

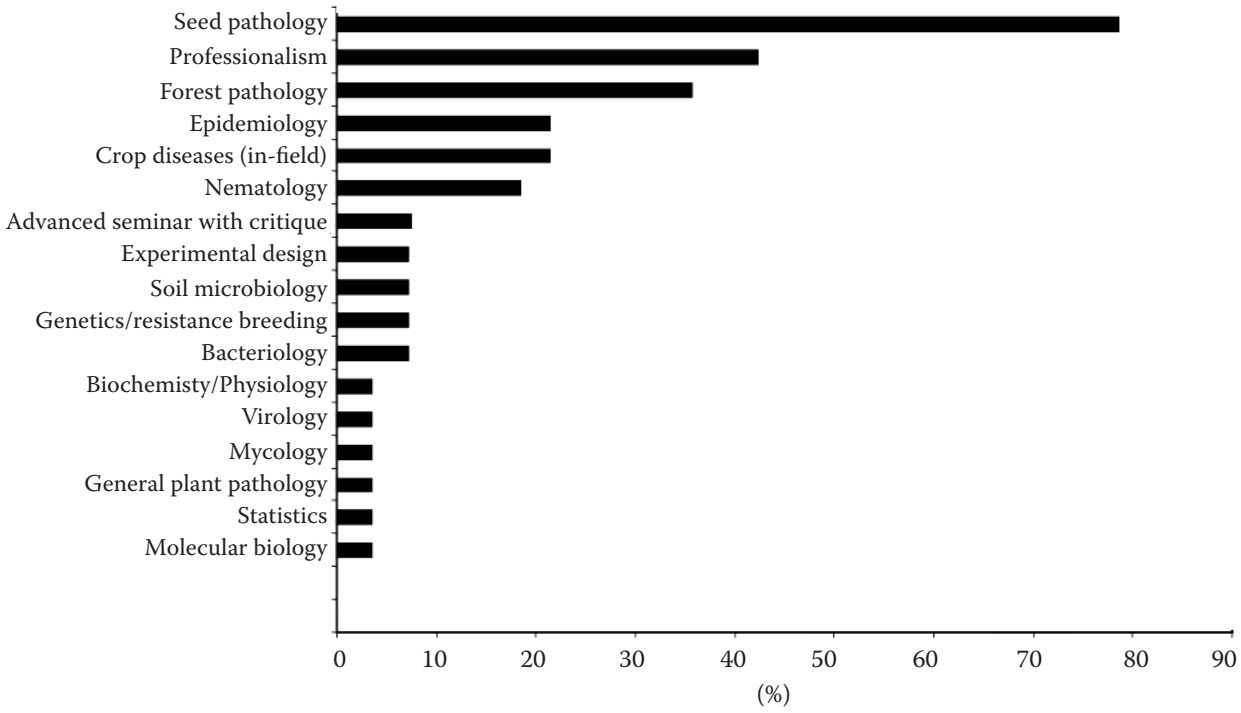

Figure 6. Percentage of departments that no longer offer selected courses in plant pathology (adapted from MacDonald *et al*. 2009)

limited availability of financial support for students (80%) (data not shown). Since graduate students are a university's 'raw materials', this does not project a bright future as the current World War II baby boomer generation of plant pathologists begin a mass exodus into retirement.

Disciplinary balance within departments

Considerable discussion and debate related to disciplinary balance within plant pathology departments has taken place for many years, e.g., faculty who conduct research in the applied, field-level

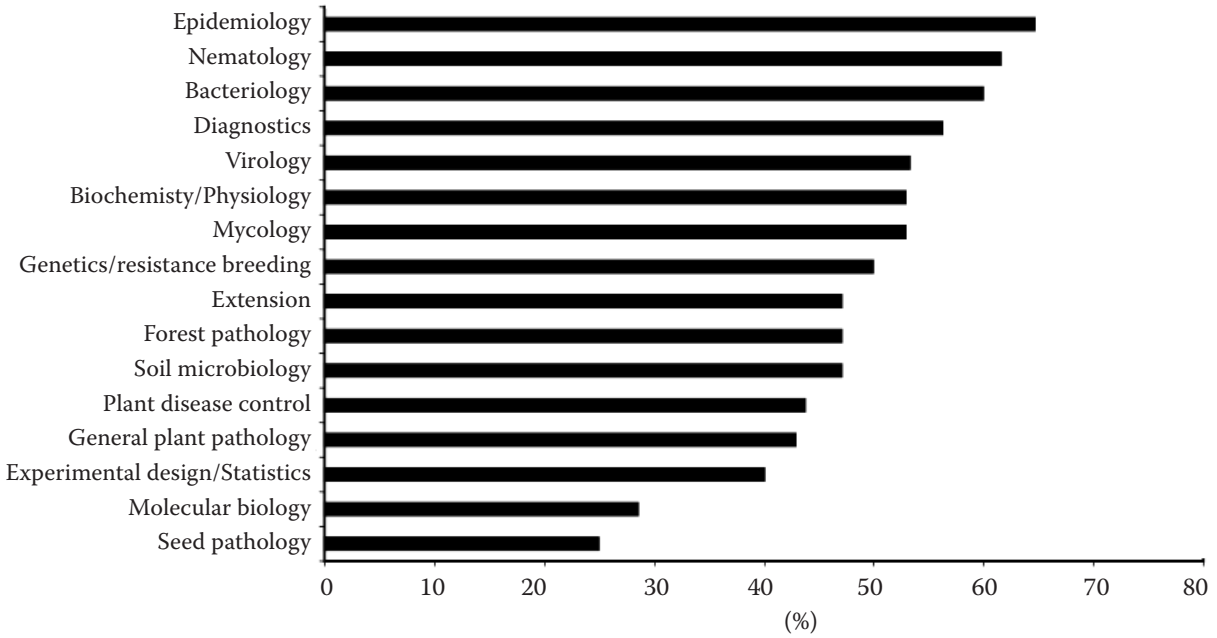

Figure 7. Percent of respondents indicating they were either fairly concerned (3) or highly concerned (4) about sustaining adequate coverage of the sub-disciplines in their department (adapted from MacDonald *et al*. 2009)

aspects of plant pathology and those who conduct research on the cellular and molecular aspects of host-pathogen interactions. This debate is not new and probably started in the early 1900s when L.R. Jones, the first president of APS, associated pectinolytic enzymes with the soft-rotting bacterium, *Erwinia carotovora,* and appealed to his colleagues at the University of Wisconsin to embrace a more cross-disciplinary approach to studies on the relationship between hosts and parasites (Walker 1979). As the science of plant pathology began moving from a descriptive era toward a more basic understanding of how plant pathogens cause disease many new questions came into view. The sub-discipline of host-pathogen interactions was born. Early pioneer leaders included J.C. Walker, E.F. Smith, W. Stanley, E. Gäumann, R.B. Goodman, D.F. Bateman, L. Sequeira, N. Keen, I.A.M. Cruickshank, J. Kuc, P.J. Allen, H. Wheeler, R.B. Pringle, R.K.S. Wood, and a multitude of others.

As research techniques became more sophisticated so did the questions. Advances in biochemical, physiological and genetic techniques paved the way for the era of molecular biology. Plant pathology had matured and specialization had come of age. We now had generalists and specialists and their research interests, techniques and vocabulary were different. Plant pathology was expanding into new realms. It is uncanny, that as we debate this today, J.C. Walker addressed this same issue in his introduction to the inaugural publication of The Annual Review of Phytopathology in 1963 (Walker 1963). His article was aptly titled "The Future of Plant Pathology". In this he writes: "*In the past two decades many new techniques have developed in physiology, genetics, chemistry, and bacteriology which can be and are being used to pry more deeply into the unsolved mysteries of plant disease.... . It is obvious that beginners in plant pathology, as well as those established in the field, if they are to stay there, must adopt these techniques and, more important, adapt them to pathological problems. The consequence of this trend obviously is more and more specialization within plant pathology. Already we see cults developing who refer to themselves as plant virologists, plant diseases physiologists, plant nematologists, microbial geneticists, and I presume just around the corner, plant disease molecular biologists.... . I am not so much concerned that plant pathology will disappear like the exploding atom.... . What I am concerned about is that these "specialty" groups will lose plant pathology.... This must not happen.*"

The shift to molecular host-pathogen interactions

Molecular host-pathogen interactions is a relatively new area of specialization within plant pathology, having its start in the 1980s, and many new plant pathology faculty hires since then have been molecular biologists. Many of these new faculty received their Ph.D. degrees in fields other than plant pathology, e.g., plant biology, molecular genetics, biochemistry, etc. Data from a 2007 census of USLGUs (Gadoruy *et al*. 2009) revealed that of the 673 total plant pathology faculty only 73% (490) had received their Ph.D. degree in plant pathology. Additionally, membership in The American Phytopathological Society (APS) was 90% for those faculty with a plant pathology degree as opposed to 81% for departmental faculty as a whole, suggesting a significant number of faculty housed in plant pathology departments do not view APS as their primary professional society. On the other hand, many are members of the International Society of Molecular Plant-Microbe Interactions (IS-MPMI) and attendance at the biannual IS-MPMI Congress has increased steadily from about 700 in 1992 to almost 1300 in 2007 (M. Bjerkness, APS, personal communication). Interestingly, almost three times as many people attend the IS-MPMI Congress as there are members in the IS-MPMI and it demonstrates the rapid expansion of molecular biology into plant pathology around the world.

The shift to a greater research emphasis on molecular host-pathogen interactions over the past two decades also can be seen by the number of research articles published in the three journals published by APS*:* Plant Disease, Phytopathology and Molecular Plant-Microbe Interactions (MPMI) (Figure 8). From 1985 to 2007, there was a decline of 29% and 36%, respectively, in the number of articles published in Plant Disease and Phytopathology, although there has been a slight increase in each the last two years. Conversely, there has been a 111% increase in the number of papers published in MPMI since its inception in 1990. The scientific impact factor of MPMI has risen steadily over the years and is currently at 4.275, placing it 10th overall among 152 journals

in the category of Plant Sciences. The number of articles published in MPMI has been relatively constant recently, however, suggesting perhaps that the journal has now matured.

A perception among many plant pathologists today is that university departments preferentially filled faculty positions in molecular host-pathogen interactions at the expense of other sub-disciplines within applied and field-orientated plant pathology, such as nematology, epidemiology, forest pathology, disease management, etc. Gadoury *et al*. (2009) provide a good discussion of this but conclude there is no evidence to suggest this occurred disproportionally beyond the initial creation of the core expertise. This also partially explains the dramatic increase in the number of articles published in MPMI during the early years of the journal and the leveling off seen in the last 7 years. They did, however, conclude that the number of scientists working in two areas of plant pathology (plant nematology and forest and shade tree pathology) has declined considerably during the past 20–25 years.

What does the future hold for plant pathology?

At this point, a few rhetorical questions might be in order. Was J.C. Walker right? Is plant pathology disappearing like an exploding atom? Will a decline in the number of plant pathology faculty at the USLGUs and an ever-increasing specialization among them, impact the discipline of plant pathology and undermine our ability to manage the multitude of plant diseases that occur around the world? Will plant pathology be reduced to just a handful of faculty members scattered among large, multidisciplinary departments of plant molecular biology? Will there be an ample supply of quality raw materials, i.e. graduate students, who can be molded into future generations of plant pathologists? Where will the next Norman Borlaug come from?

As I ponder these questions, I am struck by the irony of the situation and the similarity to the past. As the great Yogi Berra said: "*This is like déjà vu all over again*". Yes, the data suggest that there has been a significant decline in the number of plant pathologists trained and hired in the United States in last decade. And, yes, some sub-disciplines of plant pathology are losing strength and their identity at our USLGUs. And, yes, maybe we are even losing expertise in some of the applied aspects of our science. But I don't think it spells the end of plant pathology. What we are witnessing is an evolution of our science, not an extinction. Molecular biology has proven to be a powerful tool and every plant pathologist today, student or mid-career, needs to "*adopt these techniques and adapt them to pathological problems*". These new tools have allowed us to delve deeper and

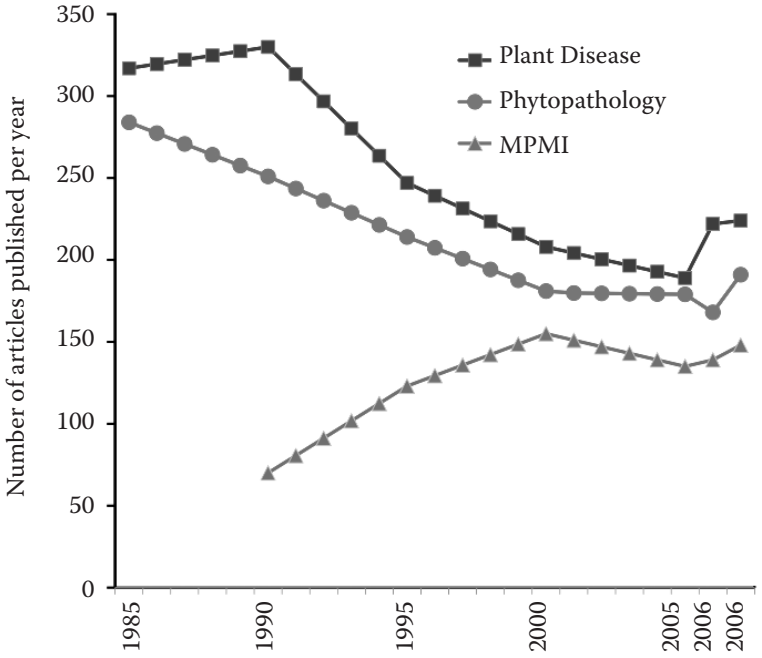

Figure 8. Number of research articles published per year in the three APS journals Plant Disease, Phytopathology and Molecular Plant-Microbe Interactions (MPMI). MPMI began as a new journal in 1990

deeper into our science, peeling back layer after layer of information and we are learning more and more. Pathogen genome sequencing, mapping and cloning of resistance genes, a molecular understanding of the determinants of virulence and pathogen effectors will undoubtedly lead to new answers and, more importantly, lead to better disease management.

What does the future of plant pathology hold? 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.

Future research likely will focus on new problems traditionally seen as outside the discipline of plant pathology. Food security will be a dominant and important driver of plant pathology research. Research into the molecular and cellular interactions of symbiotic and endophytic organisms will help provide answers to food-borne illnesses such as those caused by *E. coli* and *Salmonella* spp. and how these and other human pathogens become established in plants in the field. Additionally, the impact of climate change on plant diseases will be significant. The adaptive potential of plant and pathogen populations may prove to be one of the most important predictors of the magnitude of climate change effects (Garrett *et al*. 2006). As some parts of the world become warmer and drier some plant diseases likely will increase in severity, especially those exacerbated by abiotic stresses such as drought and salinity. Crop plants will be planted farther north than ever before and pathogens will migrate with them greatly expanding their range. Growing seasons will shift and become longer, exposing crops to diseases for longer periods of time and milder winters may allow for higher survival rates of pathogens and their vectors. And, as other parts of the world become wetter and cooler, many soilborne diseases and cool-season diseases may increase in severity. These changes will challenge agriculture even more and further exacerbate food production and supply.

Similarly, as the world's dependence on biofuels increases and new plant species are intensively cultivated for biomass production, new diseases will appear. There may be a resurgence in research in some traditional areas of plant pathology such as diagnostics, epidemiology, and disease management, as many of these diseases will be virtually unknown on their new hosts. An increased emphasis on 'green technology' also may result in increased research and a greater reliance on biologicals and SAR-inducing technologies for disease management.

Plant pathology will continue to grow as an interdisciplinary science. Collaborations with biomedical and aeronautical engineers, nanotechnologists, and computer scientists will help develop microsensory technology for the detection of new pathogens for use in biosecurity, diagnostics and epidemiological modeling. And the similarity in virulence mechanisms and pathogen effectors between plant, vertebrate and insect pathogens likely will bring new insights into human diseases and their control.

Overall, I think the discipline of plant pathology is strong and will continue to evolve. I truly believe the science and tools of molecular biology will result in better and safer disease control. Having said that, many things about traditional plant pathology at the USLGUs will change. It also should be noted that the discipline of plant pathology is not alone in this. What has been occurring in plant pathology also is occurring in a number of other applied agricultural sciences, including agronomy, entomology, plant breeding and others throughout the U.S. Each of these disciplines has experienced a decline in their traditional areas of education and research and a reduction in the number of applied faculty while expanding into the molecular age.

The National Academies (USA) appointed a special committee to examine ways in which U.S. universities and colleges should change in order to attract top students and prepare them for the challenges facing agriculture in the future. Their report (The National Academies 2009) specified nine steps for achieving change in agricultural education and included several that the APS identified years ago (e.g., broaden the treatment of agriculture in the overall curriculum; broaden the student experience; and start early). A national workshop organized by the APS held recently in Washington D.C. began discussions at the national level on the erosion of applied agricultural education and research at U.S. universities and participants included leaders from government, academia and industry.

The decline in science education appears to be occurring in other countries and in the traditional 'hard sciences' as well. For example, in the United Kingdom, 22 university physics departments and a similar number of chemistry departments have closed since 1997, leaving less than half of UK universities offering an undergraduate degree in physics (Clery 2009).

The decrease in plant pathology faculty at some USLGUs will likely continue, resulting in further erosion of departmental strengths. Departmental mergers will certainly continue; most likely in states that are losing their traditional rural economic agriculture base and becoming more urbanized, but in other states as well. This is happening already within a number of USLGUs and plant pathology may well disappear altogether at additional universities.

On the other hand, plant pathology should continue to be strong at many universities, although even the biggest departments are likely to become smaller. Retirements are not likely to be refilled at the same level of loss and those that are refilled are not likely to be filled with the same type of individual doing the same type of research. Vacated faculty positions typically are redefined by the department and/or administration to fit current opportunities and needs. A likely casualty of this is fewer positions in the traditional areas of disease management, e.g., field crops, forestry, vegetables, ornamentals, etc.

Fewer faculty undoubtedly will result in fewer graduate students and new faculty. There will be an undeniable loss in expertise and knowledge in the practice of plant pathology. It also may result in significantly fewer international students and postdocs being trained in the United States, thus, providing greater opportunities for universities around the world to become leaders in numerous aspects of plant pathology education and research.

There is a potential positive outcome from this scenario and that might be an increased appreciation for and importance of the 'doctor of plant medicine' (DPM) concept (Agrios 1992, 2001). The D.P.M. is a professional degree in the diagnosis and treatment of diseases and other conditions of plants, comparable to the doctor of medicine (M.D.) and the doctor of veterinary medicine (D.V.M.). The first such program in the U.S. was established at the University of Florida in 1999 (Plant Medicine Program) and now has over 50 students. The program and curriculum is multidisciplinary and demanding, including internships and courses in plant pathology, entomology, agronomy, weed management, physiology and nutrition of plants, soil fertility and many more. The education and training is focused, not on research, as is the Ph.D. degree, but on diagnosis and treatment. The concept has been slow in gaining acceptance and recognition; however, as research plant pathologists get further away from the field there will be a greater need for those who can diagnosis and treat plants. The D.P.M. does not compete or supplant any of the existing disciplines; rather it fills a void left by the ever-increasing specialization of each discipline.

The discipline of plant pathology will continue to evolve into a more complex multidisciplinary science. Plant pathology research and the education of future generations of plant pathologists will be different from that of today and future students will need to be more broadly trained in fields outside of traditional plant pathology. What is important is what we learn about plant diseases and their management from these new research tools and collaborations and how we communicate that to students and growers. There will always be a need for plant pathologists. We must continue to make plant pathology relevant so it does not "disappear like an exploding atom".

Acknowledgments. I am grateful to Dr. David Gadoury (Cornell University), Chair of the APS Ad Hoc Committee on the Present Status and Future of the Profession of Plant Pathology and Dr. James MacDonald (University of California, Davis), Chair of the APS Ad Hoc Committee on the Future Education of Plant Pathologists for sharing prepublication data from their respective committee reports. I also acknowledge and thank Ms. Michelle Bjerkness from APS Headquarters who provided data on IS-MPMI membership and meeting attendance and APS journal publication data.

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Received for publication June 10, 2009
Accepted after corrections June 29, 2009

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