The Genomic Revolution and Sustainable Management of Infectious Plant Disease: Aligning Policies with Objectives**

Ian Crute, Ph.D., CBE
Chief Scientist, Agriculture and Horticulture Development Board, Kenilworth, United Kingdom

Summary

Every year, persistent infectious agents and invertebrate pests cause multibillion dollar losses of crop yield and quality, as well as substantial ecological and landscape impacts (e.g., through tree disease). However, the "Genomic Revolution" is providing profound new insights into the diversity of organisms that exists in and on plants (above and below ground) as well as the sophisticated biology that plants deploy to discriminate among, and respond to, potential beneficial and detrimental invaders. This elevation of basic understanding is opening new opportunities for managing the risks posed by pests and diseases.

Plant disease management is most effective when several approaches are used to provide "integrated control": (i) use of disease-free seed or planting material (including quarantine); (ii) exploitation of genetic resistance; (iii) creation of physical, chemical, or biological environments hostile to pathogen development (e.g., use of fungicides). All three components are influenced by genomic technologies, as well as by policy and regulation. This prompts an examination of where science, policy, and societal interests are not aligned. I suggest four particular areas: (1) exploitation of plant genetic biodiversity and intellectual property protection, (2) regulation of "novel" products (e.g., crop varieties expressing new characteristics) as distinct from technology enabling their development (e.g., transgenesis/genetic modification), (3) discrimination between invasive aliens (trans-boundary immigrants) and endemic variants (e.g., virulent mutant of a long-established resident), and (4) the "market failure" of inadequate investment in "minor" or locally adapted crops of nutritional importance compared with globally traded staple crops.

Current realities

Plant pathogens (e.g., fungi, oomycetes, bacteria, viruses, and viroids) are transmitted between plants over short or long distances in four ways: (1) in or on seed, other types of propagating material, or living products (e.g., fruits or tubers); (2) contaminated soil or water; (3) air-borne propagules (such as fungal spores); and (4) animal vectors (e.g., insects and nematode worms). For brevity, the focus here is on infectious diseases of food crops; all that follows could equally apply to invertebrate pests and to nonedible plants including forest and ornamental trees. This paper also concerns the tools and technologies used to reduce the risk and magnitude of crop loss due to diseases. In particular, the science of genomics will increasingly impact on options for the detection, discrimination, and practical management of pathogens in crops, including exploitation of the plant's immune system and the diverse microbial biota that exist in association with plants. Almost all tools and technologies used to manage plant diseases are subject in some way to regulation and are influenced by policy.

Although accurate estimates are difficult to obtain, global crop losses caused by pests, diseases, and weeds probably exceed 40% of the total market. Verifiable estimates of global annual crop yield and quality loss due to crop diseases alone are at least 10%-15% — a value exceeding $75 billion. The total market for crop protection chemicals is approximately $38 billion, with fungicides accounting for approximately $10 billion. Losses caused by pests and diseases are not simply economic; human lives and livelihoods depend on predictable and reliable crop yields. Disease equates directly to wasteful, inefficient resource use (water, energy, fertilizer, land) and leads to greater greenhouse gas (GHG) emissions per unit of production.

The application of genomic science and technology (as well as policies delivering appropriately designed and proportionate regulation) can help to alleviate four constraints on meeting the above challenge. (1) Evolution is a powerful force working against sustainable disease control. Widespread use of a crop-protection chemical or deployment of a particularly effective resistance gene will select for pathogen variants that are insensitive to the control regime. As a result, efficacy will be eroded (similar to the development of antibiotic resistance). (2) New diseases and novel variants of well-recognized pathogens are frequently emerging in new regions and crops. A combination of increased global movement of people and plant products, as well as climate change, is likely the cause. (3) Societal opposition to the purported "chemical dependency" of agriculture and the returns on investment (ROI) of new chemistry are less certain, partly due to the costs associated with stringent regulatory regimes and inadequate information about potential biochemical targets for intervention. At the same time, the use of biotechnology (a substitute technology) is also being constrained by societal pressure and regulation. (4) While markets for staple crops, grown on large areas and traded internationally (e.g., maize and soy), may provide a sufficient ROI for large corporations using either genetic or chemical innovations, this is not the case for the vast majority of regionally adapted minor or "orphan" crops (e.g., fruits, tubers, and vegetables). These orphan crops are of fundamental importance in provision of a varied and nutritionally balanced diet. In summary, reducing diversity in options for control, increasing disease pressure, high costs of market entry, and uncertain ROI are leading to a focus on limited crops and disease targets by a small number of large corporations. This is not the recipe for increasing resilience to the threat of crop diseases.

Scientific opportunities and challenges

A laudable global objective is for growers to have access to an affordable set of tools enabling them to exercise reliable integrated control of the whole gamut of diseases that threaten their crops. Advances in crop and pathogen genomics bring this goal closer.

Pathogen-free planting material is the starting point, particularly for perennial crops and diseases caused by viruses and bacteria. Genomic technologies now provide the prospect of detecting, identifying, and determining the source of contaminant pathogens carried in or on seeds and other propagating material at vanishingly low levels. Proportionate systems of surveillance can be founded on sound assessments of risk and benefit and implemented by applying innovative detection technologies such that diseased material is rejected and pathogen introduction is avoided. Sole reliance on a single chemically active ingredient or a single gene for resistance does not constitute a stable, resilient control strategy. Directional evolutionary change in a pathogen population, leading to control failure, is best countered by creating system diversity. Genomic science and technology provides access to this diversity. Knowledge of plants' immune systems now provides the ability to mine genetic diversity and to identify, select, or engineer the gene sequences that will most likely provide protection against those pathogen variants to which crops will be exposed. To do this requires detailed knowledge of pathogen diversity and specifically, the sequences of genes that are essential for pathogenicity. Elevated knowledge of pathogen genomics is simultaneously enabling the identification of molecular targets for known and new chemicals with the prospect of designing a combination of molecules where evolution toward resistance would come at a debilitating or lethal cost. Genomic science is thus improving access to required chemical and genetic diversity.

In addition, how can tools and technologies be provided not just to address the most important diseases of major global crops (e.g., rice blast, cereal rusts, potato blight), but also the myriad diseases causing losses in dozens of minor crops grown for regional markets or by subsistence farmers? There is a "market failure" here, where the costs associated with investment in the necessary innovative technologies cannot provide a return because of the low economic value attributable to each of hundreds of crop and pathogen combinations. Solutions will lie in exploiting the diversity that genomic science is demonstrating as important in providing "natural" suppression of disease. Such innovations may lead to nonsaleable novel practices, promoted as public goods, as distinct from innovative products marketed for profit.

Policy issues
There are four interrelated areas of policy where applications of genomic science, reducing losses from crop disease, and the derivation of public benefit should be more closely aligned:

- Advances in genomics are revealing the enormous potential for provision of durable crop resistance to diseases through the exploitation of plant genetic biodiversity. However, this potential is not being realized because when international treaties on biodiversity and utilization of germplasm, the patenting of crop varieties, and the weak "market pull" for most crop and disease combinations are factored together, their effects are inhibitory. *National governments, working with the United Nations, must encourage the unfettered and intellectual property (IP)-free exploitation and utilization of plant germplasm for programs of both publicly and commercially funded crop genetic improvement. There should be no patent protection of crop varieties which, without exception, need to be freely available for use as parents by others.* Returns on commercial or public investment can be provided by royalties on registered varieties under internationally agreed arrangements for "Plant Breeders' Rights."

- *Multinational governance bodies need to encourage national governments to adopt policies that focus public resources on the genetic improvement of "minor" (but nutritionally important) crops* where commercial investment is low due to "market failure." National governments, by partnering and other inducements, can encourage commercial investment in crops where market returns make this an attractive and viable venture.

- Crop improvement for disease resistance has societal benefits that have been delivered through dozens of crops for over a century. Genomic science and technology provides the opportunity to make this process more effective and efficient, but it is being impeded in many countries by disproportionate and unscientific regulation of certain biotechnologies. *National governments, with the U.N., must work toward international agreements whereby crop varieties expressing well-established beneficial traits (such as disease resistance) are deregulated regardless of the technology deployed in their development.* In the case of a "novel," previously unavailable trait, the regulatory regime must focus on the impact of its use rather than the (bio)technology enabling its development.

- In the context of disease surveillance and implementation of quarantine arrangements for movement of plant materials, genomic science and technology is providing new tools and insights. *National governments, working with the U.N., need to reappraise international trade agreements that reference named plant pathogens and implement surveillance (with associated regulation) that is proportionately based on realistic, science-based analyses.* Detection of potentially damaging variants of long-established and resident organisms that express novel virulence characteristics can represent a greater (and more certain) risk than previously undetected trans-boundary immigrants.

*** A policy position paper prepared for presentation at the conference on The Genomic Revolution, convened by the Institute on Science for Global Policy in cooperation with the Parliamentary Office of Science and Technology, on September 6, 2013, within the Houses of Parliament, London, U.K.*