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Research on plant disease and pest management is essential to sustainable agriculture

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In the United States, a country with food in great abundance, it is difficult to realize that, were it not for the current level of plant disease and pest management, most human resources would be needed to obtain enough food and other plant and animal products merely to survive. Instead, there are surpluses, markets for many agricultural products are depressed, and funds available for research on plant disease and pest management—and for agricultural research generally—have plateaued or are declining.

Why does the United States need more research on plant disease and pest management? Because the health and productivity of the crops and cropping systems upon which the people depend for their own consumption and for export cannot be sustained without continuing research and development. This continued investment is needed to manage ever threatening, changing, and rebounding diseases and pest populations. Moreover, disease and pest management of the future must be improved while simultaneously reducing our dependence on pesticides as one of many steps toward the goal of sustainable agriculture.

The goal of plant disease and pest management is to ensure that crops are healthy enough to yield to their full genetic potential within the physical limits imposed by the uncontrolled variables of climate, weather, and soils. *Management* is defined as limiting damage from diseases or pests to a level at or below an acceptable economic or aesthetic threshold. This process does not require total elimination or eradication of the pest or disease problem.

by R. James Cook, Clifford J. Gabriel, Arthur Kelman, Sue Tolin, and Anne K. Vidaver

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Reducing the use of pesticides is a desirable goal, but it depends on continued and increased investments in research on alternatives. For many chemical pesticides, the alternatives either are not yet developed or are less effective than chemicals. This research must be broadly based across the biological, physical, and social sciences. Moreover, the United States and the world depend not only on sustainable agriculture but also on sustainable growth in agriculture to meet a long-term increase in demand for quality and quantity of agricultural products expected from increases in both numbers and economic status of people (Rutan 1992). Furthermore, these increases must be attained at the same time that available agricultural land is decreasing to satisfy other needs such as more land for recreation and urbanization; restoration of some wetlands, grasslands, and woodlands; and diversions of land from farming to other uses. Improved disease and pest management offers one of the few effective means by which the necessary increases in crop productivity can be accomplished while natural resources, including the remaining forests, are protected. These same principles apply to other uses of plants as well, including as ornamentals, for landscapes, and in parks and golf courses.

Diseases and pests raise economic and social problems

By all estimates, US crops could produce 15–20% more and in some cases up to 100% more on the same amount of land and with the same climate, weather, and soils, but they are prevented from doing so by unmanaged or inadequately managed diseases and pests (Boyer 1982, Cook 1986, James 1980). Equally important, the increases in productivity of crops through management of these diseases and pests could be achieved without increasing and possibly by decreasing the amount of fertilizer and water used to grow them. Unused nitrate nitrogen found in the soil profile after harvest of a crop can be indirect evidence of crop damage caused by a disease or pest (Cook 1993), because the crop is not healthy enough to use the nutrients. Regardless of the intended use of the crop—whether for food, fiber, or some industrial use—it must be healthy enough to take full advantage of the fertilizer and water available to it.

Failure to control diseases and pests can also lead to major adverse sociological effects. A classic example is the massive migration of the Irish to the United States during the last century in response to the potato famine caused by phytophthora late blight. Major plant disease epidemics still occur in the United States as well as the developing and other developed countries. In 1993, for example, fusarium head blight of wheat and barley caused crop damage in the north central states estimated to cost growers $1 billion in lower yield and poor grain quality (AP 1994). Such a short-fall in income for farmers has major economic and social effects on the communities dependent on this income. This epidemic resulted from a coincidence of frequent cropping of fields to cereals, crop residue left on the soil surface for protection of soil against erosion, and the prolonged summer rains. Not only were yields cut drastically, the infected grain contained a mycotoxin that precluded its use for food or feed.

Earlier in this century, wheat and barley were largely abandoned as crops that could be rotated with corn in Iowa and other Corn Belt states because of fusarium head blight (Dickson 1947). The same *Fusarium* causes corn stalk rot, but corn stalks left in the field provide abundant inoculum for attack of wheat and barley in this typically humid climate. Under these circumstances, wheat and barley farming in the US Corn Belt was not sustainable. Sustainability of wheat and barley farming is now seriously threatened in other areas of the US Midwest, in large part because of the necessity of farmers to practice conservation tillage.

Management of plant diseases and pests is equally critical to the preservation of our food supply after harvest to ensure that our grains, fruits, and produce do not spoil in storage and that they are free of deleterious microorganisms or their toxic metabolites such as the *Fusarium* mycotoxins in wheat and corn, which are harmful to humans or livestock (Desjardins et al. 1993, Nelson et al. 1993). Post-harvest controls are critical to protecting the food that is produced, although emphasis on post-harvest pathology as an area of research is still inadequate.

New methods needed for disease and pest management

There are at least 150 different crops grown commercially in the United States. However, most of the agricultural land is unlikely to be used to grow more than two or three crops, because of the economic and competitive advantages of farms that specialize. Fusarium head blight is but one example of many diseases and pests that have defied all attempts to bring them under control except by growing other crops in what are often uneconomical rotations. Our agricultural industries may not have the flexibility to accommodate more than minor or gradual shifts to other crops, especially in the case of a cereal-based agriculture that depends on a complex infrastructure for storage, transportation, and processing in addition to production.

Crops grown without benefit of adequate crop rotation are especially vulnerable to root damage caused by soilborne plant pathogens, including root-parasitic nematodes. For high-value crops such as strawberries in California, soil fumigation has been both more effective and economically more attractive than rotating crops or allowing the land to lay fallow long enough for soilborne pathogens to die naturally (Wilhelm and Paulus 1980). The use of soil fumigants such as methyl bromide must stop (to comply with the Montreal Protocol on reducing the use of chemicals thought to affect the ozone layer), yet effective alternatives to these treatments do not exist or are not economical. The potential exists for major shifts in competitiveness of different regions of the United States to produce fruits and vegetables because of changing economics as soil fumigants are phased out without effective alternatives. These shifts are likely to have social as well as economic and environmental impacts.

Soil fumigation has never been economically feasible on the 90%–95% of US land used to grow field crops such as cereals and oilseed crops. Other than the benefits of a limited amount of crop rotation, and some progress with host plant resistance and cultural practices, many soilborne pathogens of field crops are not managed at present. Furthermore, a significant number of soilborne pathogens can survive for two to three years or longer without host crops where minimal or no tillage is used to save or rebuild soils (Cook 1992). Soil deterioration and soil erosion caused by tillage represent serious threats to the sustainability of US agriculture (Bauer and Black 1981, Cole et al. 1989, Rasmussen et al. 1989), yet a major share of US cropland continues to depend for pest management on tillage, including many forms of intensive tillage.

The ongoing battle against the age-old fire blight of apple and pear trees, caused by *Erwinia amylovora*, illustrates another kind of problem faced by researchers and growers. Switching to new resistant varieties carries the risk that consumers may not accept them. The result is that growers continue to grow the fire blight–susceptible varieties familiar to consumers and then manage fire blight mainly by pruning out diseased branches and spraying trees with an antibiotic (van der Zwet and Beer 1991). New methods must be developed to manage head blight, fire blight, and the many other intractable disease and pest problems, and this development can only come from the results of research.

Traditional management strategies must be strengthened

One of the major success stories in the development of sustainable plant-disease management is the use of pathogen-free seed or other planting material (Baker and Linderman 1979, McGee 1981). Such planting material is obtained through seed indexing to identify and avoid pathogen-contaminated seed lots, by the production of propagative material from meristem culture, or by other methods. The new molecular tools, including monoclonal antibodies, molecular probes, and polymerase chain reaction procedures have greatly improved the means and especially the sensitivity for detecting infested or infected seeds or other planting material (Henson and French 1993). The development of new and more precise disease detection and control techniques has also given rise to many new local and regional business opportunities such as tissue-culture and seed-testing laboratories, diagnostic kits, and growers specialized in the production of pathogen-free seed.

Another major step toward sustainable agriculture is the progress in plant breeding, based on knowledge of genetics, to produce crop cultivars with resistance to diseases and pests. Virtually all major fungal leaf diseases and some insect pests that attack the foliage of the eight to ten most widely grown crop plants and many minor crop plants are or soon will be managed by the use of cultivars deliberately bred and selected to be genetically resistant to them. Wheat stem rust, a potentially devastating fungal disease, has been managed in the US and Canadian Great Plains since 1954, through strategic deployment of genes for rust resistance based on knowledge of new virulent races of the pathogen (Roelfs 1988). This method of disease management, which has lasted for 40 years, is likely to be sustained only if we recognize that new races of the pathogen continually appear and if we do not stop breeding new cultivars of wheat.

The disease responsible for the nineteenth-century Irish famine illustrates how the task of breeding resistant varieties is unending for certain diseases and must be continued. This disease, phythophthora late blight, has reemerged as a major threat to potato production in the United States and many other countries (Fry et al. 1992, 1993). Potatoes are now the fourth most important source of food in the world (Niederhauser 1993). Until recently, most of the late blight outbreaks were caused by strains of the same widely distributed mating type of the pathogen, but the other sexually compatible mating type—formerly known only in the location thought to be the geographic home of potato—is now also becoming more widely distributed. This spread increases the chances for mating and hence the appearance of new virulent strains of the pathogen with the ability to defeat genes currently in use for disease resistance. To further complicate the problems for control, this pathogen has also developed resistance to the fungicide used most widely for late blight control.

The success of the plant-breeding approach to solving crop-production problems has depended on our ability to make and deliver specific genetic changes by way of hundreds of crop cultivars. Equally important, these diverse cultivars of the approximately 150 different crops grown in the United States have been selected to fit the different local and regional environments and resist or tolerate local and regional disease and pest problems while meeting national needs. Every form of US agriculture, including organic farming, depends on and uses these cultivars developed by a network of public and private plant-breeding programs and based on modern genetics. As a minimum, this network of plant-breeding programs must be maintained.

Unfortunately, certain diseases such as fusarium head blight, root rots, and diseases caused by insect-vectored viruses have not been manageable by traditional plant breeding. Beginning approximately 30 years ago, methods such as embryo rescue and other cellular and cytological techniques made it possible to transfer alien genes for disease or pest resistance from wild and weedy relatives into crop plants. This transfer has involved the use of the so-called wide cross, chromosome substitution, and chromosome manipulation (Appels et al. 1992). The new tools of recombinant DNA technology now allow for access to and introduction of even more traits for disease and pest resistance (Fitchen and Beachy 1993, Meeusen and Warren 1989). New approaches to genetic management of diseases and pests that heretofore have defied management by traditional breeding would greatly reduce US dependency on intensive tillage, open-field burning, soil fumigants, insecticides, and fungicides. Use of the more precise tools of recombinant DNA technology to deploy a specific trait for resistance to a plant pathogen or pest also offers the potential for improving the performance of familiar varieties of fruits and vegetables without changing the appearance, flavor, or other characteristics that make them the favorites of consumers.

Biological control: The unmet potential

Biological control with natural enemies and beneficial plant-associated microorganisms (NRC 1989) holds enormous but still largely unmet potential as a component of integrated plant disease and pest management. The full use of this approach requires that we develop or select and deploy thousands, if not tens of thousands, of disease-, pest-, and/or environment-specific natural enemies and plant-associated microorganisms inhibitory or suppressive to diseases or pests (Cook 1993). During the past roughly 100 years, 850 natural enemies of insect pests and weeds have been released in the United States, of which approximately 40% have become established in the environment and are providing some level of biological control of targeted insects or weeds.[1] Managing populations or the harmful activities of the plant pathogenic microorganisms in the environment with beneficial microorganisms is even more difficult than managing populations of arthropod pests with beneficial insects. Much more research is needed to make greater use of this ecologically sound and proven method for managing pests and plant diseases.

Some of the greatest needs and opportunities for biological control are the soilborne plant pathogens responsible for root diseases, wilts, and premature blights of plants. Research has only begun to reveal the nature of the myriad interactions between pathogens and their antagonists in soil and the rhizosphere, and much more work remains to be done before these interactions can be managed for biological control. Having the knowledge and technology to control pathogens consistently and effectively in the rhizosphere using other microorganisms would help greatly to move agriculture toward sustainability.

In addition to the direct benefits of improved plant disease and pest management to the health, well-being, and productivity of agriculture, the basic research needed to achieve these goals can lead simultaneously to better understanding of ecosystems, of the interactions among diverse species or organisms, and of life processes more generally. Thus, the study of biological control of insect pests has provided much of the theory and principles available to understanding and predicting the predator-prey relationships in the environment. Similarly, information from the study of plant disease epidemics has provided much of the theory available for understanding and predicting the fate of new genotypes of microorganisms introduced into the environment (Teng and Yang 1993). The only predictable

[1]J. R. Coulson, 1995, personal communication. USDA Agricultural Research Service, Beltsville, MD.

aspect of the benefits of basic research is that new applications are likely to arise in often unpredictable ways.

Science has only begun to scratch the surface in the discovery, development, and implementation of new methods of disease and pest management. The new tools of biotechnology combined with traditional breeding; release of natural enemies and beneficial plant-associated microorganisms; and cultural practices based on knowledge of the ecology of crops, pests, and biological control agents offer virtually unlimited potential for both basic research and providing the practical disease and pest management needed to meet the goal of sustainable agriculture for the future.

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