Consultative Group on International Agricultural Research

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Study Paper Number 25

Plant Quarantine and the International Transfer of Germplasm

Donald L. Plucknett
Nigel J. H. Smith

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The World Bank
Washington, D.C.

First printing September 1988

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Library of Congress Cataloging-in-Publication Data

Plucknett, Donald L., 1931-
Plant quarantine and the international transfer of germplasm / Donald L. Plucknett and Nigel J.H. Smith.
p. cm. -- (CGIAR study paper, ISSN 0257-3148 ; no. 25)
Bibliography: p.
ISBN 0-8213-1102-6
1. Plant quarantine. 2. Germplasm resources, Plant. 3. Plant breeding. I. Smith, Nigel J. H., 1949- . II. Title.
III. Series: Study paper (Consultative Group on International Agricultural Research) ; no. 25.
SB980.P59 1988
632'.93--dc19 88-22645
CIP

ABSTRACT

A concerted, worldwide effort to boost and sustain agricultural yield has greatly increased the demand for new sources of breeding material for crop programs. To adapt crop varieties to more difficult marginal environments and to surmount the ceaseless attack of pests and diseases, crop breeders need a constant supply of fresh genes to develop more productive and resilient varieties. The spectacular growth of genebanks, where plant genetic resources are conserved and evaluated, has also accelerated the tempo of plant material exchange. Unfortunately, quarantine services have not always been able to keep pace with the growing volume of international shipments of plant breeding materials, nor the latest changes in virulence and distribution of plant pests and diseases.

This paper reviews the history of quarantine services, discusses principles for successful quarantine operations, identifies major constraints to the exchange of plant materials due to quarantine restrictions and procedures, and explores some of the difficulties faced by quarantine services, plant breeders, and genebank curators in attempting to detect diseases or pests and clean up seeds and vegetative materials. We examine disease and pest screening techniques, with an emphasis on emerging biotechnologies that are revolutionizing diagnostic and cleanup work for plant germplasm. The importance of intermediate quarantine, particularly for tropical cash crops, is underscored. Finally, we analyze ways to strengthen quarantine services worldwide so that crop improvement programs can operate more efficiently and effectively.

ACKNOWLEDGMENTS

We would like to thank the following individuals for making helpful comments on earlier versions of this paper: E.T. Beauchamp, C.W. Campbell, T.T. Chang, L. Chiarappa, D. Dalrymple, C. Farrar, E. Feliu, R.A. Frederiksen, D.W. Gorbet, D.J. Heinz, J.F. Karpati, D.A. Knauft, C.J. Krass, J. Lyman Snow, T.M. Mew, R.L. Plaisted, D.W. Puckridge, L.H. Purdy, C.O. Qualset, W. Sandige, K.G. Singh, J.C. Wynne, and F.W. Zettler. Opinions expressed in this paper are the authors' views and do not imply endorsement by the reviewers or any institution.

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GLOSSARY OF ABBREVIATIONS

AID	United States Agency for International Development
APHIS	Animal and Plant Health Inspection Service
APPPC	Asian and Pacific Plant Protection Commission
ASEAN	Association of South East Asia Nations
AVRDC	Asian Vegetable Research and Development Center
CATIE	Centro Agronomico Tropical de Investigacion y Ensenanza
CENARGEN	Centro Nacional de Recursos Geneticos
CIAT	Centro Internacional de Agricultura Tropical
CIFC	Centro de Investigacao das Ferrugens do Cafeeiro
CIMMYT	Centro Internacional de Mejoramiento de Maiz y Trigo
CIP	Centro Internacional de la Papa
COSAVE	Comite Tecnico Ad-Hoc en Sanidad Vegetal para el Area Sur
CPPC	Caribbean Plant Protection Commission
DANIDA	Danish International Development Agency
ELISA	Enzyme-Linked Immunosorbent Assay
EPPO	European and Mediterranean Plant Protection Organization
FAO	Food and Agriculture Organization
IAPSC	Inter-African Phytosanitary Council
IBPGR	International Board for Plant Genetic Resources
ICARDA	International Center for Agricultural Research in

SUMMARY OF POLICY RECOMMENDATIONS

Successful quarantine operations rest on solid scientific research, appropriate legal measures and accords, and efficient administration and logistics. Here we summarize policy recommendations for improving quarantine services worldwide. We highlight pressing needs which should be met to boost the scientific competence and administrative efficiency of quarantine operations.

Scientific aspects:

---More research is needed on the life cycle, host range, and natural history of crop pests and pathogens so that their quarantine risk can be better assessed.

---Virology and nematology are two particularly weak areas in many quarantine services.

---Post entry quarantine sites should be well isolated from areas where the crop is grown to reduce the chances of an escaped pest or disease becoming established.

---More intermediate quarantine facilities are needed for tropical plantation crops and some vegetatively-propagated food crops.

---More quarantine services need to add capability to handle plant materials in tissue culture, the preferred form for shipping many vegetatively propagated crops.

---Quarantine services need to accelerate the integration of emerging biotechnologies, particularly novel methods for detecting pathogens, into their work so that plant materials can be processed more quickly.

---When genebank accessions are regenerated or evaluated, clean up procedures should also be included to reduce the chances of shipping pathogens or pests.

Administrative/logistical aspects:

---Some quarantine services, particularly in large countries with diversified and dynamic agricultural economies, would benefit from decentralization in order to reduce processing bottlenecks.

---Closer cooperation between quarantine services is needed, particularly on a regional basis, to harmonize regulations and facilitate the exchange of plant materials.

---Greater flexibility in handling borderline quarantine cases is warranted when the material in question is an endangered species, or if it is likely to contain valuable genes needed to combat a serious crop threat.

---National quarantine services that process large germplasm shipments generated by international agricultural research centers generally need increased support from the international community in order to handle the growing volume of germplasm shipments more efficiently.

----More national quarantine services would benefit from microcomputers at ports of entry that are linked to databases containing information on the latest distribution and virulence of crop pests and pathogens.

---More support is needed for training people from developing countries who wish to pursue careers in quarantine work.

---More training opportunities are also needed for individuals in the Third World who wish to pursue graduate training in disciplines that are frequently tapped by quarantine services, such as mycology, malacology, entomology, virology, bacteriology, weed science, and biotechnology.

I. INTRODUCTION

The international exchange of plant germplasm has increased spectacularly over the last few decades. At the same time, concern has arisen that the risk of spreading crop pests and diseases has also increased. International agricultural research centers and their cooperators, in particular, send out vast quantities of seeds and other plant parts all over the world. For example, the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) based near Hyderabad, India, has sent over four million seed samples around the world since 1974 (Varma and Ravi, 1984).

Plant breeders generally recognize that precautions are necessary to prevent or slow the spread of pests and pathogens[1], but have sometimes questioned the ability of quarantine services both in industrial countries and the Third World to handle the increased workload. Tensions have arisen between plant breeders and genebank curators who are understandably eager to obtain plant material as quickly as possible, and quarantine officers who see themselves as the first line of defense against the invasion of foreign crop pests and pathogens. Both camps should be working in harmony, but that is not always the case. Quarantine services are sometimes accused of not keeping pace with scientific advances, including new diagnostic tools, and of being unfamiliar with the disease picture for certain crops. On the other hand, breeders and other crop scientists are sometimes accused of circumventing quarantine procedures to obtain plant materials for their work.

The increased international distribution of germplasm poses real hazards for crop production worldwide (Karpati, 1981, 1983). For example, in germplasm collections in the United States alone, some 17 crop species have been found to harbor seed-borne viruses (Doyle, 1985:203). Seed-borne viruses have also been found in germplasm collections of barley (*Hordeum* spp.), cherries (*Prunus* spp.), beans (*Phaseolus* spp.), pea (*Pisum sativum*), and lentil (*Lens culinaris*) (Mandahar, 1981; Hampton, 1983). Several pathogenic viruses of potato (*Solanum tuberosum*), such as Potato Yellow Vein Virus, Andean Potato Latent Virus, and Andean Potato Mottle Virus, as well as Potato Spindle Tuber Viroid, have been found in European potato genebanks (Jones, 1983). In a 1978 test of 36 potato accessions in the germplasm collection maintained by the Bolivian Institute of Agricultural Technology at Toralapa, 72 percent were found infected with one or more viruses; 42 percent contained Potato Virus X, while 28 percent were infected with Potato Virus Y (Christie et al., 1983). Some soybean (*Glycine max*) accessions in germplasm collections in the United States are contaminated with soybean mosaic virus, an economically significant pathogen (Irwin and Goodman, 1981).

Depending on the plant species and reason for importation, quarantine services may allow plant materials in without prior inspection, release the materials after checking documentation or treatment, or detain them for further observation. Grains destined for milling are sometimes fumigated before a ship leaves port and may be inspected on arrival, whereas vegetable seeds are generally exempt from quarantine restrictions. Fruit imported for consumption, on the other hand, is often inspected and treated prior to shipment, particularly if the fruit is grown in the importing country. Germplasm for breeding purposes is usually inspected and sometimes screened by quarantine services; in some cases, it is denied entry.

The list of plants subject to quarantine procedures is daunting. Currently, 125 countries prohibit one or more plant species, and over 240 crops or plant species are prohibited from entering at least one country (Kahn, 1982). Some 1,585 different pests and pathogens are targets of quarantine services worldwide. This danger list includes 614 different insects and mites, 46 nematode species, 537 fungi, 96 bacteria, and 292 viruses. Over 1,300 pests and pathogens have been listed as a significant threat to U.S. crops (Mathys, 1977). The potato alone has approximately 266 pests and pathogens (Smith, 1983). Quarantine officers understandably have a hard time keeping abreast of the status and potential danger of myriad crop pests and pathogens.

Quarantine officers, however conscientious, can never hermetically seal any agricultural area against the importation of pests or pathogens. The pace and magnitude of travel alone threaten to overwhelm even the most vigilant quarantine service. Approximately 800 million people annually board flights on 500 scheduled airlines to 6,000 destinations in 150 countries*; some airline passengers unwittingly convey crop pests or pathogens in their baggage, or uninvited pests hitch a ride in the cargo hold or cabin. At least 200 million airline passengers fly internationally every year, and plant materials occasionally pass through customs without being inspected. In 1941, hardly a major year in commercial aviation, 227 insect species were found in commercial aircraft worldwide (Adamson, 1941), and by now that figure has surely grown considerably. Furthermore, efforts to control pest movement, such as spraying insecticide inside aircraft as a public health measure, are not nearly as common as they were prior to the 1970s. First class mail is a major headache for state quarantine officials in the United States, particularly in California and Hawaii. First class mail cannot be opened for inspection by state officials, and plant materials are sometimes knowingly or unwittingly sent in this manner.

Air cargo and military flights are other avenues for circumventing quarantine. Air freight, which is liable to inspection, can slip by quarantine inspection when the airway bill is false or incomplete. The marked trend towards containerization of air and sea freight to reduce costs complicates the work of quarantine officials. Inspectors cannot easily penetrate tightly-packed containers to check for plant materials and pests; a thorough search entails removing the contents, resulting in delays and higher costs for shippers. Military flights are sometimes scheduled at short notice or use remote airfields, and quarantine officials may not always be alerted concerning arrivals. In the case of Hawaii, the state quarantine service is stretched to cover military flights and arrivals at international airports on the islands of Oahu, Hawaii, Maui, and Kauai.

Several hundred million tons of grain are annually shipped worldwide, opening further avenues for spreading crop pests and pathogens. Food grain shipments are usually milled soon after arrival, but on the way to the mill some grain typically spills from trucks and boxcars, and volunteer plants may then sprout. In May 1981, for example, the roadside from Tuxpan to Mexico City was festooned with spontaneous sorghum (Sorghum bicolor) plants that had sprouted from grain falling from trucks carrying sorghum imported from the United States. Also, some rice (Oryza sativa) is shipped as 'rough rice' which still has the husks (glumes) attached to the seed; millers often discard the husks which can harbor pathogens (P. Jennings, pers. comm.).

Cases abound where plant germplasm contaminated with a pathogen or an arthropod pest has eluded quarantine. Viruses are a particular problem in this regard because they are invisible to the naked eye, symptoms of infection can be confused with plant nutrient deficiencies, and because some viruses are slow to act. Citrus nursery stock, infected with the virus that causes tristeza disease, was imported to Argentina and Brazil from Australia and South Africa and led to the destruction of some 20 million trees in the 1940s (Knorr, 1977). Peanut stripe virus was first detected in the United States in 1982 at the Regional Plant Introduction Station in Experiment, Georgia; it apparently entered the U.S. in groundnut (Arachis hypogaea) germplasm imported from the Peoples' Republic of China (Demski et al., 1984; PCRSP, 1984:6). By 1983 the virus had spread to groundnut nurseries in Georgia, North Carolina, Florida, Virginia, and Texas, all major groundnut producing states. Bacterial pathogens of crops are also hard to detect and can easily slip into a country. Cassava bacterial blight undoubtedly reached Africa and Asia from tropical America by way of planting stakes infected with the pathogen, Xanthomonas manihotis (Lozano, 1977).

Mutations occur frequently with many pests and pathogens. Furthermore, their distributions may change rapidly, so quarantine services are sometimes equipped with outdated information, to the detriment of agricultural science throughout the world. Pathogens may have already reached a country by truck, plane, wind, or other means, and yet quarantine services may still prevent the importation of certain plant materials or so delay their release that the viability of the germplasm is jeopardized.

Quarantine services are understandably conservative. When in doubt, they generally prohibit the importation of questionable material or destroy it. Herein lies much of the concern of crop scientists with quarantine services worldwide. Still, few would dispute that quarantine has a vital role to play in preventing or delaying the economic losses that typically accompany the introduction of foreign pests and diseases.

This paper reviews the impact of quarantine on the exchange of plant germplasm by briefly examining the history of quarantine efforts, outlining principles of successful quarantine operations, and pinpointing cases where quarantine measures impede breeding programs. Our purpose is to bring quarantine issues to the attention of donors and administrators concerned with promoting increased agricultural production. Quarantine officers will hopefully find the discussion useful, particularly with regards to ways to upgrade quarantine operations. Finally, scientists involved in crop breeding and plant protection may benefit from exposure to quarantine-related problems in virology, bacteriology, mycology, and nematology, and become more sensitive to the legitimate concerns of plant quarantine operations.

No attempt is made here to "take sides" in the disputes that may arise between quarantine officers and crop scientists. Rather, we emphasize the need to form a closer partnership particularly between plant breeding and quarantine by exploring the interface between scientific developments and quarantine work. We identify some of the problems in screening germplasm for pests and pathogens in order to underscore the complexity of quarantine work and to emphasize that good research and a high level of scientific competence are vital for its success. Pest and pathogen screening procedures for germplasm are reviewed, with particular emphasis on emerging biotechnologies that promise to revolutionize plant quarantine work. Finally, we suggest ways to strengthen and streamline quarantine services worldwide.

II. HISTORY OF QUARANTINE SERVICES

Screening germplasm for pests or pathogens by government agencies at ports of entry is relatively recent. Only a handful of nations systematically checked imported plant material for pathogens prior to this century (Adamson, 1941). Concern over the possible spread of the Colorado potato beetle (Leptinotarsa decemlineata) from the United States spurred the establishment of quarantine regulations in Germany in 1873 and the United Kingdom in 1877 (Mathys and Baker, 1980). The U.K.'s 1877 Destructive Insects Act was broadened in 1907 and 1927, and then consolidated in the 1967 Plant Health Act. Australia enacted plant quarantine legislation in 1909, while at the urging of the nursery trade, Denmark established a plant protection service in 1913 (Neergaard, 1986).

In the United States, the California legislature passed the first quarantine law when it granted such authority to the Board of Viticulture Commissioners in 1881 (CDFA, 1980:2). In 1890, quarantine coverage was broadened in California when a horticultural quarantine officer was appointed. The first U.S. national quarantine legislation became effective in 1905 with the passage of the Insect Pest Act. This act was prompted by the refusal of Texas to collaborate with California in keeping Mexican oranges out of California. California had embargoed Mexican oranges in 1899 in an attempt to prevent the spread of the Mexican fruit fly and sought permission from Texas to post quarantine officers in Brownsville and El Paso. Texas refused on the grounds that such a move would infringe on state sovereignty.

The Insect Pest Act coincided with the establishment of the Office of Foreign Seed and Plant Introduction in Washington, D.C., which began systematically checking imported plant materials, including seed, budwood, and nursery stock, for pests in 1905 (Hyland, 1977). Incoming material given a clean bill of health was sent to several regional plant introduction stations for evaluation. Building on the Insect Pest Act, the Federal Plant Quarantine Act of 1912 tightened quarantine regulations by stipulating that nursery stock could only be imported from countries maintaining an inspection service (Cunningham, 1984:176). The 1912 Plant Quarantine Act was triggered by outbreaks of pine blister rust, chestnut blight, and citrus canker (Waterworth and White, 1982).

The Plant Quarantine Act was amended in 1917, 1926, and 1957 to address specific problems arising from the increased flow of germplasm to the United States. The 1957 amendment authorized emergency actions to prevent the introduction or interstate movement of plant pests and pathogens not covered by previous legislation. Furthermore, the amendment encompassed insects, slugs, fungi, parasitic plants, viruses, and other organisms that can damage growing plants or processed plant products.

In the early part of this century, plant collectors sometimes fretted about the fate of their painstakingly garnered materials after shipment home. They worried whether the dispatched materials would survive the journey and pass the scrutiny of quarantine officers. Frank Meyer, a legendary American plant collector in the early part of this century, complained vigorously about new quarantine restrictions imposed by the recently formed Office of Foreign Seed and Plant Introduction. Meyer protested to his boss, David Fairchild, another avid plant collector, that the new regulations would "throw out the baby with the bathwater" (Cunningham, 1984:221). The stipulation that germplasm samples should be fumigated and thoroughly cleaned prior to shipment to the United States was making exploration for economic plants increasingly difficult by 1916.

Currently, all plant materials entering the United States are inspected by officers of the Animal and Plant Health Inspection Service (APHIS), Plant Protection and Quarantine. Based on the findings of APHIS personnel, the material may be released, treated, quarantined, reshipped, or destroyed. Prohibited or restricted plants are quarantined at the Plant Introduction Station, Beltsville, Maryland, where new facilities became operational in stages starting in 1986 as the old facility at nearby Glenn Dale was phased out. The Beltsville facility concentrates on asexually-reproduced materials, such as potatoes, which are checked for latent diseases through two cropping cycles. APHIS began virus indexing of introduced vegetatively propagated crops in 1957. Other restricted materials enter through 14 plant inspection stations located strategically throughout the United States.

Quarantine services in developing countries are even younger than those in industrial nations and are often far from comprehensive with regard to the range of pests and pathogens they are equipped to screen for. Brazil passed its first quarantine regulations in 1934 (Law 24, 24 April) and quarantine now falls under the jurisdiction of the National Center for Genetic Resources (CENARGEN--Centro Nacional de Recursos Geneticos) in Brasilia (Lins, 1987). India had a Destructive Insect and Pest Act in 1914, but it was only implemented in 1936. The Indian quarantine service only started checking incoming seeds for pests and pathogens in 1985 following passage of the Plants, Fruits, and Seeds Order of 1984 (Paroda et al., 1987). For the most part, quarantine services of developing countries are only a few decades old. The Philippines quarantine service, for example, began operating under a seed quality control program in 1954, but comprehensive screening of seeds for pests and pathogens only started in 1968 (Sevilla and Mamicpic, 1987). Prior to 1968, screening of seeds by the Philippines quarantine service was restricted to fungal pathogens.

Quarantine services, whether in industrial nations or in the Third World, are more effective when they coordinate activities and regulations. The first international effort to erect a quarantine blockade was triggered in Europe by a grapevine pathogen, Phylloxera vastratix. The Phylloxera convention was signed in 1881. Unfortunately, most signatories lacked the facilities and scientific expertise to implement the convention (Mathys and Baker, 1980).

Efforts to standardize quarantine procedures received a strong boost in 1951 at the Sixth Conference of the United Nations Food and Agriculture Organization (FAO) in Rome. The International Plant Protection Convention (IPPC) was approved at the conference to facilitate quarantine work and was subsequently signed by 44 countries. The number of adherents to IPPC grows constantly: in the early 1980s, 75 countries were signatories, by 1985, 83 countries had joined, and by 1987, the number of participating nations reached 89 (Kahn, 1970, 1982; Chiarappa, 1985; E. Feliu, pers. comm.). Amendments to the convention were approved by the FAO conference in 1979, but they still await implementation (FAO, 1987:8). The IPPC has encouraged the establishment of several regional quarantine organizations, such as the Asia and Pacific Plant Protection Commission (APPPC) which is coordinated by a FAO plant protection officer in Bangkok (see table 1).

Latin America and the Caribbean are particularly well endowed with regional plant health organizations. The Caribbean Plant Protection Commission (CPPC) serves the Caribbean Region, much of northern South America, as well as France, the Netherlands, the United Kingdom, and the United States. The Organismo Internacional Regional de Sanidad Agropecuaria (OIRSA) spans Central America, while the Comite Tecnico Ad-Hoc en Sanidad Vegetal para el Area Sur (COSAVE) covers Argentina, Bolivia, Brazil, Chile, Paraguay, and Uruguay. The Junta del Acuerdo de Cartagena (JUNAC), headquartered in Lima, Peru, helps coordinate plant quarantine regulations between Bolivia, Colombia, Ecuador, Peru, and Venezuela. To facilitate germplasm flow from different ecological zones, some Latin American countries belong to more than one regional plant protection organization. Thus Venezuela participates in JUNAC and CPPC. All regional plant protection organizations receive guidance from FAO and most issue periodic pest data sheets.

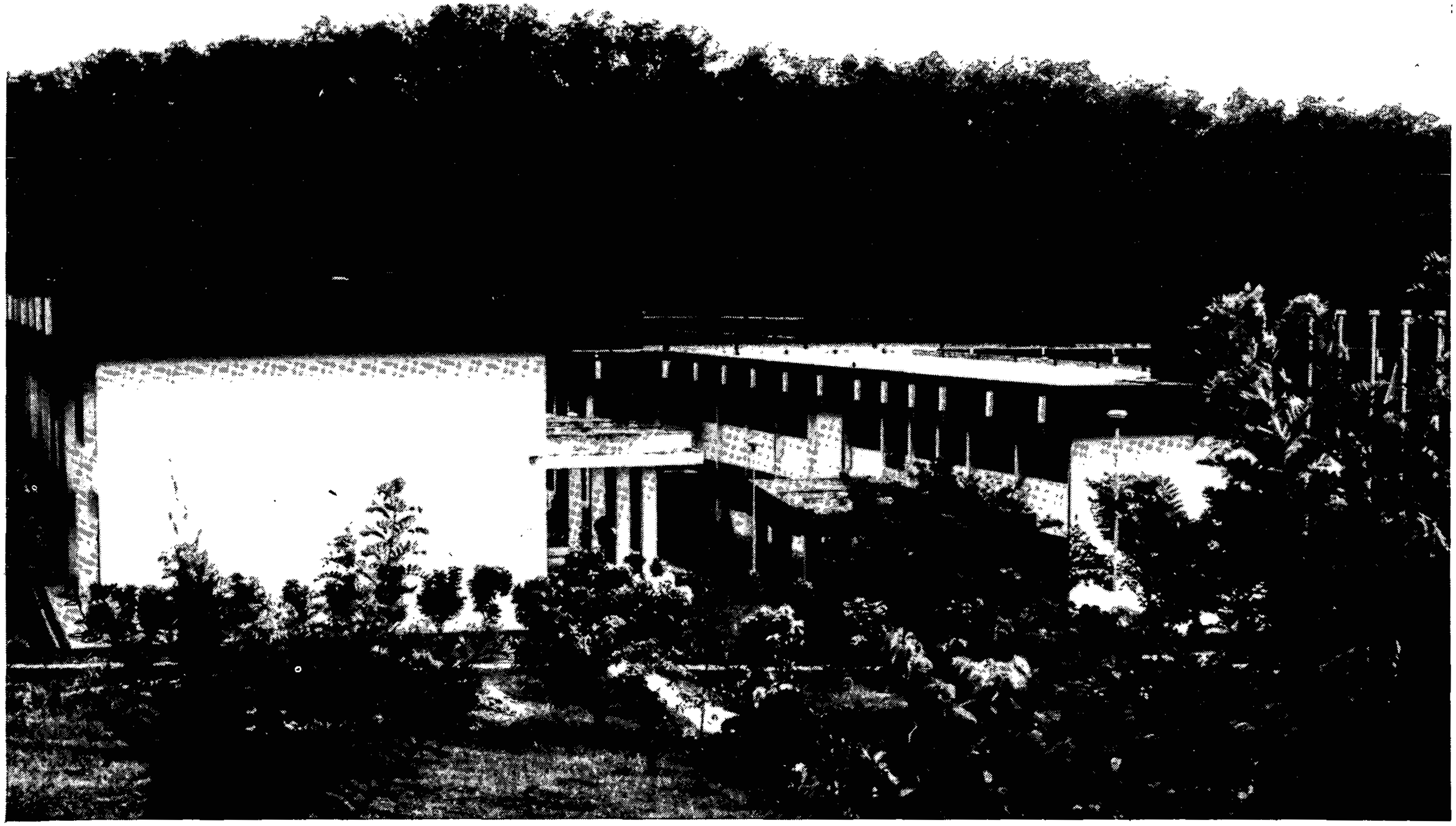
Other regional plant protection organizations that work closely with FAO include the Inter-African Phytosanitary Council (IAPSC), set up in 1962, and the Paris-based European and Mediterranean Plant Protection Organization (EPPO) which was launched in 1950 (see table). EPPO harmonizes quarantine regulations between 36 member countries, including the Soviet Union (Mathys, 1977). The Washington, D.C.-based North American Plant Protection Organization (NAPPO) strongly advocates the safe and efficient transfer of plant germplasm (E. Feliu, pers. comm.).

Table 1. **Regional Plant Protection Organizations**

Organization	**Acronym**	**Member Countries**	**Headquarters**
Asia and Pacific Plant Protection Commission	APPPC	23	Bangkok, Thailand
Caribbean Plant Protection Commission	CPPC	18	Port of Spain, Trinidad
Comite Tecnico Ad-Hoc en Sanidad Vegetal para el Area Sur	COSAVE	6	Montevideo, Uruguay
Junta del Acuerdo de Cartagena	JUNAC	5	Lima, Peru
Organismo Internacional Regional de Sanidad Agropecuaria	OIRSA	7	San Salvador, El Salvador
Inter-African Phytosanitary Council	IAPSC	48	Yaounde, Cameroon
North American Plant Protection Organization	NAPPO	2	Washington, D.C.
European and Mediterranean Plant Protection Organization	EPPO	36	Paris, France

With the assistance of the U.S. Agency for International Development (AID), the ASEAN (Association of South East Asian Nations) Plant Quarantine Center and Training Institute (PLANTI, Figure 1) near Kuala Lumpur, Malaysia, publishes up-to-date information on changes in the distribution and virulence of pests and pathogens and helps establish common quarantine standards for Brunei, Indonesia, Malaysia, Philippines, Singapore, and Thailand, all ASEAN countries (Singh, 1983). West African quarantine needs are largely met by the Plant Quarantine Center in Ibadan, Nigeria.

Figure 1. Main offices and classrooms of the ASEAN Plant Quarantine Center and Training Institute (PLANTI), near Kuala Lumpur, Malaysia, 1986.



International and regional plant protection organizations are useful forums for discussing mutual problems and for devising strategies to help stem the spread of plant pests and pathogens, but their record is inconsistent. The IPPC remains vague since the convention merely stipulates that plants or parts thereof moving in international trade should be substantially free of economically significant pests and diseases (Mathys, 1977). In an effort to increase the effectiveness of IPPC and strengthen measures designed to ensure the safe movement of germplasm, FAO organized an informal consultation of regional plant protection organizations in Rome from 19-22 May 1986 (E. Feliu, pers. comm.). Another problem with regional organizations is that political differences may flare up and impede the smooth flow of germplasm. The East African Plant Quarantine Station at Muguga, Kenya, was established to serve Kenya, Tanzania, and Uganda (Berg, 1977), but with the breakup of the East African economic community, the station now mostly processes material for Kenya and several international agricultural research centers.

The relatively late arrival of plant quarantine services and their varying effectiveness fuel arguments that quarantine is more of a hindrance than a help to agricultural research and development. It is certainly true that most of the important crops have been cultivated widely for thousands of years, so many pests and pathogens have had ample opportunities to spread. People have been exchanging plants for millennia and many crops were taken to new lands during the colonial period. Until quite recently, plant hunters, missionaries, diplomats, and others dispatched materials home where they were generally planted with no quarantine screening. For many diseases and pests, then, the damage has already been done; plants and their diseases and pests were carried far from their areas of origin long before quarantine cordons were set up. In spite of these arguments, however, quarantine services are clearly needed to prevent or slow the dispersal of new pests and races of existing pathogens and damaging insects. Numerous serious pests and diseases are still confined to relatively restricted areas, and quarantine services have an important role to play in trying to prevent their spread.

III. QUARANTINE PRINCIPLES

Effective quarantine work hinges on the successful orchestration of scientific, administrative, and legislative inputs. Insufficient attention to one area, such as scientific research, can quickly lead to wasted opportunities to enrich a country's crop breeding programs or to the release of harmful pests or pathogens. Effective quarantine work hinges on efficiently-applied administrative measures that are grounded in solid scientific research.

Morschel (1971) proposed eight premises fundamental to plant quarantine: (1) quarantine measures should be based on sound biology, (2) quarantine should not be used to hinder trade, (3) quarantine services must derive from adequate law and authority, (4) quarantine operations should be modified as conditions change or more facts become available, (5) the objective of preventing introduction and spread of a pest or pathogen must be feasible, (6) professionals and the public must cooperate on an international scale, (7) quarantine officers must be well informed, and (8) quarantine services are only one facet of domestic pest management and should be integrated with other pest and disease control measures. These principles have been endorsed and expanded on by Mathys and Baker (1980) and Waterworth and White (1982).

Here we focus mainly on scientific premises outlined above (1, 4, 5, 7), and suggest some additional scientific and administrative principles for sound quarantine work. We emphasize six major principles, three concerned with biological issues and the remainder with administrative aspects of quarantine work. We stress the following principles for successful quarantine operations: (1) a wide range of scientific disciplines needs to be tapped, (2) pests and pathogens need to be ranked according to their importance and chances of becoming established, (3) quarantine of plants should be conducted in areas isolated by ecological conditions from the respective crop-growing areas, (4) quarantine services should be reasonably flexible, (5) quarantine services are more efficient and effective when decentralized, and (6) quarantine facilities require access to good communication and transportation services.

Expertise in a wide range of disciplines is required in order to assure a solid scientific basis for quarantine decisions and to assess effectively the risks of releasing germplasm. Ideally, specialists with training in virology, bacteriology, mycology, nematology, malacology, entomology, botany, and weed science should be incorporated in plant quarantine services. When such expertise is not available in-house, arrangements should be made with universities and research laboratories for the services of scientists to identify specific pests and pathogens and to assess their potential to become established and spread.

A multidisciplinary approach when collecting germplasm also facilitates quarantine work. Teams assembled to collect germplasm of crops and their near relatives should include plant pathologists in addition to taxonomists and genetic resource specialists (Neergaard, 1984). By ruling out diseased germplasm at its source, the chance of introducing pathogens inadvertently is reduced.

Quarantine work is streamlined when pests and pathogens are ranked according to their potential danger to crops. Regulations should focus on serious economic pests and pathogens that are unlikely to arrive by natural dispersion (Fry, 1982:133). The EPPO, for example, focuses its efforts on pests and pathogens causing significant damage to economically important crops that are unlikely to reach member countries by natural dispersal (Mathys and Baker, 1980). Germplasm from centers of diversity for particular crops should be a high priority for quarantine officers, since such material is likely to harbor more diseases and species of pests as well as more races of each pathogen and pest (Neergaard, 1977, 1984). Unless formidable geographic barriers exist, such as high mountains, germplasm from a neighboring country does not normally warrant such special scrutiny since pests and pathogens often disperse naturally across shared political boundaries. Pests or pathogens that are unlikely to become established for climatic or other reasons should also be struck from quarantine lists. Diseases or pests that are unlikely to become important should not receive as much weight in quarantine decisions as those that present a significant economic risk. It should be kept in mind, however, that ranking pests is not an easy task. Pest behavior in one location is not always a reliable indicator of its potential impact in another area. Reliable rankings will require sound scientific research and, usually, international cooperation, to ensure a greater understanding of the organism concerned and its potential for damage and spread.

In cases where germplasm must be planted and periodically inpsected before it can be safely released, observation is best conducted well away from areas where the crop is grown, at least on a commercial scale. In this manner, an escaped pest or pathogen is likely to perish since most crop pathogens and pests are species-specific. To help prevent the spread of flag smuts, among other diseases, exotic wheat germplasm imported into the United States is sown in a detention nursery in Arizona, well separated from major wheat-growing areas in the Midwest and Northwest. Rice germplasm imported into the United States is grown under observation in a part of southern California where rice is not cultivated, or in glasshouses in Beltsville, Maryland (Parliman and White, 1985). Ideally, plant quarantine facilities should be well separated from production areas by ecological barriers such as extensive deserts, sizeable bodies of water, or high mountains.

Occasionally, introduced materials may be grown in or near a major production area for the crop. For example, plant introduction stations where material is quarantined are sometimes located in areas where the crop is grown because of more favorable growing conditions. This is a major advantage in the case of germplasm received in poor condition that might perish under less than optimal conditions. The U.S.D.A. Plant Introduction Station in Experiment, Georgia, handles imported groundnut germplasm and is situated on the perimeter of the groundnut-growing area in the southeastern part of the country. In such cases, special precautions are necessary to prevent the accidental release of an exotic pest or pathogen.

On the administrative and infrastructure side, flexibility is essential to the success of quarantine work. Quarantine officers should be allowed a certain amount of discretion when passing judgement on materials. Sufficient scientific data or expertise for an informed decision may not always be available; some leeway is therefore necessary when appraising the risk of releasing plant material. The ideal is not always possible and risks must be minimized, within reason (McCubbin, 1946). In borderline situations, germplasm should probably be cleared if the agricultural problem it is targeted for is especially urgent. Considering the alarming spread of black sigatoka disease among banana and plantain plantations in Africa and Latin America, for example, some discretion in allowing more international exchange of germplasm with possible resistance genes is warranted. Also, it may be wise to give endangered germplasm the benefit of the doubt since its habitat is threatened. In such cases, release of the germplasm to scientists working closely with the crop may be the best recourse, provided that quarantine officials make periodic on-site inspections.

The Netherlands quarantine service is exemplary in striving to find solutions for handling questionable germplasm shipments without lowering standards (J. Hardon, pers. comm.). Quarantine services can be more flexible when introducing germplasm to small islands or other geographically isolated areas since any resulting damage can be more easily contained (Zwolfer and Harris, 1971). Flexibility requires regular and rigorous self-examination by quarantine services, keeping staff abreast of scientific developments, and overhauling regulations to reflect the dynamic nature of pests and pathogens.

Quarantine operations are generally more efficient when they are decentralized. In this manner, material is handled more quickly since it can be imported through more than one port of entry. Furthermore, it is unlikely that all the expertise required to pass judgement on germplasm will be concentrated at one location. A decentralized approach puts material in the hands of competent scientists with special expertise in the crop pest or pathogen in question. Decentralized operations, however, must ensure that high standards are maintained throughout the system. Special attention is particularly important when individuals from organizations other than the state or national plant quarantine service are authorized to perform some quarantine work.

Several countries have partially or fully decentralized quarantine systems. The United States has a relatively decentralized quarantine set up; grape germplasm sent to the University of California at Davis is quarantined on the Davis campus, while rice germplasm brought to California is quarantined under supervision of the USDA Agricultural Research Service at a facility in the Imperial Valley. Citrus germplasm imported into California is quarantined at the University of California, Riverside, under the watchful eye of the Pest Exclusion Service of the State Department of Food and Agriculture. On the other side of the country, APHIS oversees intermediate quarantine work on cacao (Theobroma cacao) conducted by the USDA Subtropical Horticulture Research Station in Miami.

Plant quarantine is also decentralized in India, a sensible approach for a large country with a dynamic and highly diversified agriculture. In addition to the Directorate of Plant Protection, Quarantine, and Storage, three other organizations are authorized to perform quarantine work: the National Board for Plant Genetic Resources (NBPGR), the Forest Research Institute, and the Botanical Survey of India (Paroda et al., 1987). NBPGR, headquartered in New Delhi, concentrates on quarantine of field crops, while the Forest Research Institute in Dehradun quarantines forestry species. The Calcutta-based Botanical Survey of India is empowered to quarantine species not covered by other institutions.

Under authority of NBPGR's regional office near Hyderabad, ICRISAT quarantines germplasm imported for its mandated crops in a six hectare post-entry plot. This plot is located in one corner of ICRISAT's 1,394 hectare property and is surrounded by a 45 hectare belt of uncultivated land (Varma and Ravi, 1984). Quarantine work at ICRISAT was previously conducted under the supervision of the Central Plant Protection Training Institute on the outskirts of Hyderabad (Neergaard, 1984), but as of August 1986, this task was assumed by NBPGR. ICRISAT's seed health unit is responsible for checking the germplasm destined for international nurseries, as well as material brought in for its own breeding programs in sorghum, pearl millet (Pennisetum typhoides), chickpea (Cicer arietinum), pigeonpea (Cajanus cajan), and groundnut.

In the Philippines, a scientist at the Los Banos-based International Rice Research Institute (IRRI) has been deputized by the Bureau of Plant Industry to issue phytosanitary certificates for rice germplasm destined for export and is responsible for checking imported materials. Conflict of interest does not appear to be an issue at either ICRISAT or IRRI since individuals involved take their responsibilities seriously and do not wish to jeopardize the convenient arrangements with the national plant quarantine authorities, nor the integrity of the seed exchange programs of their institutes.

Easy access to major communication networks, including telephone, telex, road, and regularly-scheduled airlines, is vital to the smooth operation of quarantine services. Delays in receiving germplasm can threaten its viability. Major urban centers usually enjoy superior transportation facilities, and quarantine stations are best located there. The USDA Subtropical Horticulture Research Station in Miami has emerged as a major intermediate quarantine center for certain tropical cash crops, a role envisaged for the Tropical Research Station at Mayaguez, Puerto Rico, but never fully realized because, unlike Miami, Mayaguez is not a major hub of communications. Furthermore, important cities and towns are more likely to have reliable supplies of electricity, essential for maintaining controlled growing conditions for quarantined material. Also, it is generally easier to secure technicians and engineers near urban areas to operate and service sophisticated laboratory equipment.

IV. BOTTLENECKS

Complaints have arisen, both from breeders and quarantine officers, about various aspects of quarantine work. Loss of germplasm during quarantine has stirred concern since the inception of quarantine operations. Some germplasm of cacao relatives (*Theobroma speciosum*, *T. subincanum*, and *T. simiarum*), for example, was lost in quarantine in Trinidad during the early part of this century (Williams and Williams, 1951:297). In some cases, though, germplasm arrives in such poor shape that it is not surprising that it fails to survive. Rather than try to affix blame when germplasm exchange is unsuccessful or impossible due to quarantine actions, we attempt to pinpoint problem areas for discussion. Furthermore, rather than cover exhaustively all the cases where dissatisfaction has been expressed, we select examples from various areas of quarantine work. We take an historical perspective while sampling problems from a variety of crops in different countries.

Quarantine restrictions can sometimes make life difficult for crop breeders who want to enrich their breeding pools with fresh genes. When germplasm is released by quarantine authorities it may have deteriorated due to delays in shipping or processing. Sometimes breeders are unable to obtain new germplasm due to temporary or permanent bans on the importation of certain plant material. Ironically, stringent quarantine regulations, albeit based on legitimate concerns to prevent an agricultural catastrophe, sometimes prevent the importation of new material needed to upgrade crop vigor and yield stability.

Problems encountered by breeders in obtaining germplasm from quarantine services span both industrial and food crops. Of the 103 countries with suitable climates for growing citrus, for example, 62 prohibit the importation of citrus germplasm in one form or another. Of the countries strictly regulating the entry of citrus germplasm, nearly half deny entry to both seeds and plants.

Only scion-wood cuttings of citrus can be imported into the United States, and such materials are typically quarantined for several years. Such strict measures handicap citrus breeders trying to incorporate resistance to diseases, pests, and adverse environmental conditions into modern cultivars. Orange groves in Florida, for example, have been badly damaged by hard freezes in 1983 and 1984, particularly in the northern extension of the state's orange-growing area. Cold tolerant varieties would benefit the Florida citrus industry, but thus far the response to freeze damage has been to replant with young orange trees or to switch to other crops.

Florida's $1.2 billion citrus industry was dealt another severe blow in 1984 when a new strain of citrus canker, caused by a bacterial pathogen (*Xanthomonas campestris* pv. *citri*), turned up in several nurseries

(Schoulties et al., 1987). Over nine million orange trees were burned between August 1984 and August 1985 in an effort to halt the spread of the nursery form of citrus canker. The Asiatic strain of citrus canker was found in several house-yards and a commercial grove in Florida in 1985 and 1986. Eradication efforts are expected to continue for at least five years at an estimated cost of $70 million[3]. How the pathogen got into the state remains a mystery, but it was not the first time. An epidemic of citrus canker in Florida from 1912-1927 stemmed from the importation in 1910 of infected nursery stock from Japan. That outbreak cost $6 million and led to the burning of 3.3 million citrus seedlings and trees (Knorr, 1977). Since there is no effective chemical means of controlling the pathogen, and the bacterium periodically eludes the quarantine blockade, cultivars need to be developed that are genetically resistant to the disease. Sources of resistance to citrus canker have been located in wild germplasm of citrus, but breeders are reluctant to tap such sources because of the protracted effort that will be required to transfer the desired genes into agronomically suitable lines. Still, someday such a breeding effort may be undertaken, and quarantine concerns will have to be dealt with in a reasonable fashion if the desired germplasm is to be imported and used.

Quarantine regulations also impede the work of coffee (Coffea spp.) breeders (Rodrigues, 1977). Properly treated coffee beans are relatively safe for transferring genetic resources, but in the case of robusta coffee (C. canephora), the identity of a coffee variety is lost in seed due to genetic recombination in the progeny. Breeders rely heavily on vegetatively propagated material to transfer coffee varieties, including arabica coffee (C. arabica). A few field genebanks have been established for the crop, but germplasm exchange is limited by quarantine restrictions, among other factors. Coffee germplasm cannot legally be imported into 49 countries, including a number of major coffee producers (Kahn, 1982). A major goal of such quarantine restrictions is to halt the spread of coffee rust (Hemileia vastatrix). This orange-colored fungus is endemic to Africa and has ravaged coffee plantations in Asia; it wiped out commercial coffee production in Sri Lanka in the late 19th century (Purseglove, 1974:476). In spite of quarantine vigilance, the rust disease gained a foothold in Brazil in 1970, possibly after wind dispersal of spores from Africa or on imported germplasm, and by 1983 had penetrated Colombia and Central America[4].

Germplasm exchange of tea (Camellia sinensis) is also impeded by quarantine regulations. East African countries, for example, prohibit the importation of tea seeds or seedlings from outside Africa (Kahn, 1967); this measure poses problems for breeders since the crop originated in Asia. Similarly, avocado (Persea americana) breeders in the United States cannot obtain any more germplasm from Mexico or South America because of quarantine restrictions. Avocado originated in the American tropics and plant explorers, particularly Wilson Popenoe, brought traditional varieties from Central and South America to California and Florida to start the lucrative avocado industry in those states. Peach and plum breeders in the United States encounter difficulties importing seed of their crops because of disease concerns and cannot obtain seed from areas known to harbor the plum pox virus.

New problems surface with crops all the time, further complicating the work of breeders and quarantine officers. In the case of cacao in Malaysia, for example, cocoa pod borer (Conopomorpha cramerella) began damaging the crop in Sabah in 1981. The larvae of this lepidopteran pest tunnel into cacao pods and thus escape pesticide treatment. This development is serious because cacao is the third most important export crop in Malaysia, and germplasm can no longer be safely exchanged between Sabah and the mainland. As a precaution, Malaysia halted the importation of cacao germplasm from other parts of Southeast Asia. But such restrictive measures ultimately proved futile; cocoa pod borer reached the Malaysian peninsula in 1986 (J.F. Karpati, pers. comm.).

Direct importation of rubber (Hevea spp.) germplasm to Southeast Asia from South America is prohibited outright in an effort to keep South American leaf blight (Microcyclus ulei) from attacking extensive and highly profitable plantations of Hevea brasiliensis in the region. Seedlings of H. brasiliensis were taken from the Amazon basin to Asia via the United Kingdom's Royal Botanic Gardens, Kew, in the late 1800s; fortunately they did not carry the fungal pathogen which defoliates rubber trees and still prevents the establishment of sizeable rubber plantations in its native home. More recently, several Asian nations collaborated in the acquisition of more rubber seeds. The collected seeds were germinated in Malaysia and observed there for any disease symptoms. Healthy scion-wood is being distributed to India, Indonesia, and Sri Lanka (R. Litz, pers. comm.).

To protect the flourishing rubber industry in Southeast Asia, which produces over 90 percent of the world's crop, countries in the region only allow the import of rubber germplasm if it has passed through an intermediate quarantine station outside of the American tropics (Turner, 1977a). Thailand, in turn, will only allow entry of rubber germplasm if it comes from Malaysia. Malaysia's concern about South American leaf blight and its own stringent quarantine standards against the fungus are immediately apparent at Kuala Lumpur's modern airport where prominent neon-light signs warn arriving passengers of the danger of bringing in rubber germplasm. Indonesia outlaws the importation of any vegetative propagating materials of Hevea (PLANTI, 1986).

Triticale, a man-made cross between wheat and rye, holds considerable promise for boosting food production in the Third World. Already, this nutritious cereal is grown extensively in some industrial countries, principally for livestock feed. But adoption of the high-yielding cereal in developing regions has been slowed in part because of quarantine concerns (Oram et al., 1979:31). Confusion arises because quarantine officers are not sure whether to classify the new crop as wheat or rye and therefore which quarantine regulations to follow.

Wheat breeders in the United States and Canada are currently having a hard time obtaining germplasm from Mexico due to the presence of Karnal bunt, caused by the fungus Neovossia indica (syn. Tilletia indica), which attacks seeds of wheat and triticale. Mexico is home to the International Maize and Wheat Improvement Center (CIMMYT--Centro Internacional de Mejoramiento de Maiz y Trigo) which maintains a large collection of wheat germplasm (Plucknett et al., 1987). Some of the materials are of interest to U.S. breeders; one indication of the historical importance of wheat germplasm exchange between U.S. institutions and CIMMYT is the fact that close to one quarter of wheat lands in the United States contain some germplasm from CIMMYT's world collection (Wennergren et al., 1986).

Karnal bunt was first recorded in northwestern India in 1931 and has since spread across northern India and into Pakistan, Afghanistan, and Iraq (Joshi et al., 1983). The pathogen was first noted in northern Mexico in the Yaqui Valley, Sonora, in 1971 and the disease was confined to that state until the mid-1980s (Prescott, 1984). Recently, the pathogen appears to have spread to neighboring states. Some scientists claim that Karnal bunt was a minor disease of wheat until adoption of high-yielding varieties which are highly susceptible to the pathogen (Lambat et al., 1983). But some traditional wheat varieties on the Indian subcontinent may be susceptible to Karnal bunt, and recent genetic changes in the pathogen may account for its increased virulence.

In 1983, APHIS banned all shipments of wheat germplasm from Mexico after a few Karnal bunt-infested grains were discovered in a box car containing honey from Mexico at Calexico on the border between California and Mexico. Canadian authorities quickly followed suit. These moves were prompted by the fear that wheat exports might suffer if the pathogen became established in the United States and Canada (Kahn and Hopper, 1984). It is likely, however, that upper winds, hurricanes, or migrating birds have carried spores of Karnal bunt into the United States and Canada for at least 15 years with no apparent effect. Furthermore, until the 1983 ban, wheat seeds destined for breeding purposes have been trucked annually since the mid-1960s from Mexico to the Upper Midwest and Canada. Ecological conditions may not be suitable for Karnal bunt in the United States and Canada.

The clamp on wheat germplasm exports from Mexico stirred concerns about the future of wheat breeding programs in Mexico and the U.S. (Curtis, 1985). However, APHIS relaxed the 1983 ban to allow a limited transfer of experimental wheat materials. If wheat germplasm comes from Karnal bunt areas, the seeds must be grown in glasshouses. Wheat seeds from non-Karnal bunt areas of Mexico can be grown in open fields in the U.S. (C.O. Qualset, pers. comm.).

The international exchange of pulse (grain legume) germplasm is also adversely affected by quarantine regulations. Groundnut breeders in the United States cannot send germplasm to some countries for fear of spreading peanut stripe virus (D. Gorbet, pers. comm.). The world collection of groundnut germplasm maintained by ICRISAT near Hyderabad, India, would undoubtedly contain more valuable accessions, particularly of wild species, if quarantine restrictions were not so stringent.

Sometimes germplasm is destroyed after it has entered a country to prevent the possible spread of pests or pathogens. In 1984, approximately one thousand groundnut breeding lines were destroyed in the field at the University of Florida, Gainesville, because they were suspected of harboring peanut stripe virus. This drastic measure set back groundnut breeding in Florida by several years and has slowed the production of new varieties for peanut growers in the southeastern U.S. In 1987, ICRISAT had to destroy some groundnut lines because they had become infected with peanut stripe virus, apparently introduced to ICRISAT's grounds in materials obtained from a collaborating local university (J. Wynne, pers. comm.). In 1947, a large collection of wild potatoes (Solanum demissum, S. stoloniferum, and S. varrucosum) from Mexico was destroyed at Sturgeon Bay, Wisconsin, because the recently established potato introduction station did not have sufficient facilities at that time to screen the imported material for pathogens (Correll, 1967).

Plant materials are sometimes deliberately or inadvertently destroyed by plant quarantine officers at ports of entry. Some IRRI rice lines entering the Malagasy Republic, for example, have been summarily destroyed without checking to see whether the material was contaminated (ISNAR, 1983:119). Fortunately, the Malagasy Republic quarantine service has recently improved with the construction of post-entry glasshouses. Some plants succumb to treatments or processing delays. In June 1986, for example, several tomato plants were killed by a pesticide in the plant quarantine center in Bangkok, Thailand. Samples that are spared from destruction may linger for months or years before they are released.

The large volume of germplasm shipments generated by the international agricultural research centers sometimes swamps national quarantine services, thereby resulting in processing delays. Even if plant materials are still viable when they are eventually released, urgent breeding projects may have been put on hold. Curators of forage genebanks in Europe often experience lengthy delays in obtaining germplasm for their collections (UNDP/IBPGR, 1984:6). Potato breeders in the Netherlands must wait at least eight months before potato germplasm is released by quarantine authorities (Doyle, 1985:206), whereas potato germplasm imported into the United States undergoes two growing cycles before it is released by APHIS. Other crop breeding programs in the United States experience delays in obtaining the release by APHIS of materials sent by international agricultural research centers (D. Dalrymple, pers. comm.). Most fruit tree germplasm entering the United States is grown under quarantine observation for four to six years (Waterworth and White, 1982). If incoming plant material is found by quarantine services to be contaminated with viruses, clean-up efforts further delay its release.

Quarantine services sometimes release only a small subsample of a germplasm shipment after inspection, treatment, or growing out under observation in order to reduce the chances of letting a pathogen slip by. Bean breeders at CIAT (Centro Internacional de Agricultura Tropical), near Cali, Colombia, are allowed to draw only draw 10 seeds per accession from the center's genebank in order to comply with Colombian quarantine regulations (M. Holle, pers. comm.). Such low numbers may restrict genetic diversity of those seeds, since some potentially valuable genes are likely to be rare in any given population. Thousands of seeds are usually needed to represent a reasonably good sample of the genetic diversity within a heterogeneous population. By restricting the number of seeds and progeny released by quarantine services, germplasm destined for breeding purposes may suffer from the 'founder effect' in which a small founding population has squeezed through a bottleneck that inevitably excludes some genes. The smaller the genepool, the fewer potentially useful characteristics that are available to the breeder.

V. DETECTION PROBLEMS

The generally conservative nature of quarantine services is partly due to the fact that many pathogens are difficult to detect with current techniques. To play it safe, then, quarantine services often opt to prohibit the importation of germplasm or hold back materials for extended periods, thereby reducing their viability. Breeders may complain that quarantine services are overly restrictive, but the task of screening germplasm for diseases and pests is not always easy. Here we cite a few cases to illustrate the difficulty of detecting crop pathogens in germplasm samples.

A major difficulty for plant quarantine officers is that germplasm infected with pathogens may not exhibit any symptoms, particularly in the case of certain nematode-transmitted viruses (Bos, 1977). With aphid-transmitted viruses, an infection rate as low as 0.1 percent in seeds can lead to heavy losses by harvest time if vectors are numerous (Bos, 1985). Some viruses that attack citrus remain latent for up to eight years (Kahn, 1967). Growing out material for prolonged periods of observation is costly and slows down breeding programs.

Some pathogenic fungi and bacteria can also remain dormant in seeds for extended periods, complicating the work of quarantine officers and genebank curators. Most smut fungi can remain dormant as mycelia for up to 50 years. Dormancy in such fungi is favored by the cold, dry conditions of genebanks. Chickpea seeds may harbor at least five pathogens, including such destructive fungi as Ascochyta rabiei and Fusarium oxysporum f. sp. ciceri, which cause ascochyta blight and fusarium wilt respectively, and yet not show any evidence of disease (Kaiser, 1984; Haware et al., 1986:3). Bacteria such as Xanthomonas phaseoli, the agent of common blight of bean, and Corynebacterium flaccumfaciens, can remain viable in bean seeds for as long as 15 years (Neergaard, 1977). A high proportion of cassava seeds infected with the cassava bacterial blight pathogen, Xanthomonas campestris pv. manihotis, exhibits no sign of infection by this organism (Lozano and Jayasinghe, 1983). Many pathogenic fungi and viruses are borne inside seeds and thus escape chemical treatment; this applies particularly to leguminous crops such as beans and alfalfa, chenopods (such as quinoa, an Andean grain crop), potato, tomato, and members of the rose family, which includes the apple (Kahn, 1979).

Another complication for quarantine officers is that some pathogens that attack crops have not yet been identified, or if they have been described, detection methods have yet to be developed. This is especially the case with viruses (Berg, 1977). Until a virus has been identified, probes cannot be tailored to detect it. IRRI scientists find new viral pathogens of rice every few years;

the same holds for virus diseases of citrus (Knorr, 1977). Even when a virus has been isolated, indexing procedures to detect the virus often have not been perfected. The movement of primitive banana and plantain germplasm from Southeast Asia and the Pacific is hampered because no indexing methods are available to screen Musa plant materials for the presence of bunchy top virus (IBPGR, 1986:4).

Pathogens and insect pests that are well known can change into virulent new forms-- witness the spectacular outbreaks of fungal and bacterial diseases as well as increased insect damage to crops due to mutation. The brown planthopper (Nilaparvata lugens), for example, has evolved at least three biotypes in rice fields of Southeast Asia.

Importation of germplasm of wild species, which are becoming increasingly important in crop breeding, is particularly difficult for quarantine services to approve. Little is usually known about the prevalence of potential crop pests and pathogens in natural habitats (Figure 2). Tropical forests, where some important cash crops such as rubber, cacao, and African oil palm (Elaeis guineensis) were domesticated, are especially poorly understood in this regard. Further, some seeds destined for genebanks and breeding programs are obtained in local markets, so collectors do not know whether the seeds were harvested from healthy plants.

Figure 2. Collecting wild Pennisetum grass, a relative of pearl millet, in Malawi for germplasm collections. Courtesy of the International Board for Plant Genetic Resources (IBPGR), Rome.

VI. DISEASE AND PEST SCREENING METHODS

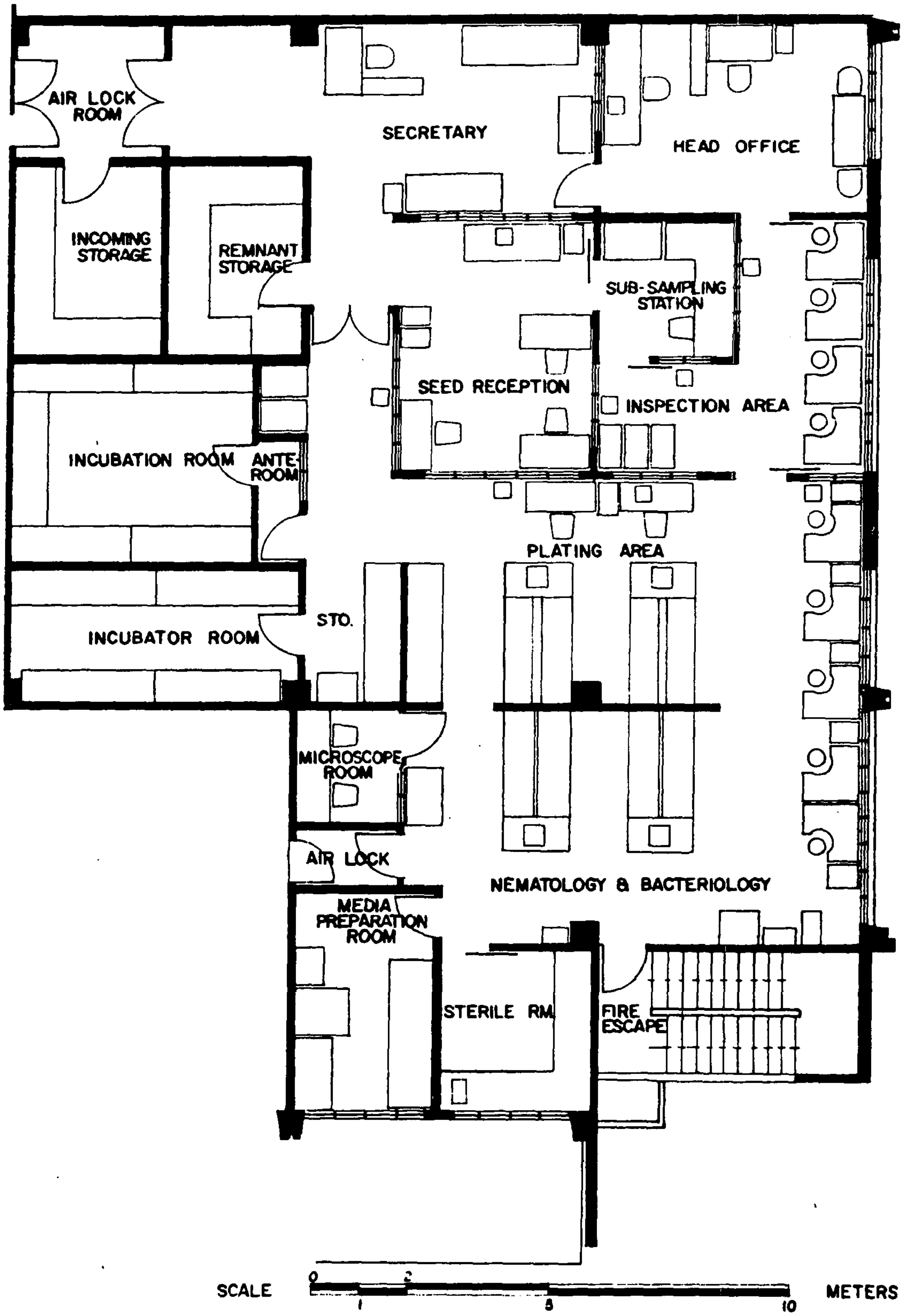
Germplasm for breeding programs or genebanks must normally pass through at least two checkpoints before it arrives at its destination. First, germplasm is usually checked for pests, diseases, and extraneous soil or plant material at the institution dispatching the samples. National quarantine services are then approached to secure a phystosanitary certificate for exporting treated and healthy-appearing material. Sometimes, international agricultural research centers are given authority to issue such certificates, usually by deputizing one of the staff. This practice is generally followed by CIMMYT, the International Potato Center (CIP--Centro Internacional de la Papa), ICRISAT, and IRRI. Phytosanitary certificates identify the material and explain what treatments and tests were employed in preparing the samples for export. Then, at the port of entry, quarantine services may release, treat, grow out, or destroy the material. In this section we explore methods for eliminating pests and pathogens from germplasm destined for export and testing and clean-up procedures at ports of entry.

Plants for generating seed or other material for export are often grown in areas relatively free of pests and diseases to reduce the chances of shipping infected germplasm. Much of the seed for common bean (Phaseolus vulgaris) planted by farmers in the United States, for example, is produced in southern Idaho where dry weather discourages many fungi, bacteria, and insects (Kaiser, 1984). Irrigation methods or other crop management practices, however, can nullify otherwise advantageous growing conditions. For example, sprinkler systems, rather than water-conserving drip irrigation, can counteract the advantages of arid climates in suppressing crop pests and diseases, however. Agricultural research centers sometimes use relatively pest-free substations, or specially treated plots within a substation, to produce materials for exchange. CIMMYT employs its Ciudad Obregon substation in the state of Sonora, a dry region in northwestern Mexico, to produce wheat seed for distribution to international nurseries. At Ciudad Obregon, materials for producing seed destined for inter-regional or international shipment are grown in separate plots and are regularly sprayed with pesticides. As a further precaution, seeds are only harvested from vigorous, unblemished plants. And at the International Institute of Tropical Agriculture (IITA) in Ibadan, Nigeria, soybean and cowpea (Vigna unguiculata) seeds destined for multi-location testing are grown during the rainy season when aphids--vectors for various plant viruses--are at their lowest population levels.

After seed destined for germplasm exchange is gathered, it must undergo further scrutiny. To accommodate the ever-growing volume of seeds distributed to international nurseries and directly to breeding programs, several international agricultural research centers have recently established or expanded seed health facilities. The International Center for Agricultural Research in the Dry Areas (ICARDA), near Aleppo, Syria (Figure 3) set up seed health facilities in 1982. IRRI also set up its seed health facility in 1982, although outgoing seeds at IRRI had been systematically tested for pests and pathogens since the seed unit was created in 1980 (Chang et al., 1987). IRRI's seed health facilities were upgraded in 1986 when the new Biotechnology and Seed Health Building was inaugurated (Figure 4). Seed health facilities at CIAT and CIMMYT came on line in 1984. Seed health facilities at international centers draw heavily on staff from various research programs. The CIMMYT seed health unit is assisted by many of the center's scientists; 15 of the 29 staff in the wheat program, for example, are trained primarily in plant pathology (Curtis, 1985). Some international centers and many national agricultural research programs still do not have seed health units. IITA, for example, has been seeking funds for a seed health unit since 1984.

Figure 3. Seed health unit at the International Center for Agricultural Research in the Dry Areas (ICARDA), near Aleppo, Syria, 1984.

Figure 4. Floor plan of the expanded seed health facilities inaugurated at the International Rice Research Institute (IRRI), Los Banos, Philippines, in 1986.



All wheat seeds destined for CIMMYT-coordinated international nurseries are individually inspected for signs of Karnal bunt at the center's headquarters in El Batan, Mexico; grains with the dark grey powder characteristic of Karnal bunt infections are discarded. The remaining grains are treated with a variety of chemicals to kill fungi and other pathogens and pests. This screening operation is a major undertaking, considering that over 600,000 packets of wheat seeds are prepared every year for dispatch to approximately 100 countries.

IRRI also uses a variety of techniques to clean up germplasm shipments. After fumigation, immersion in hot water, passing through a machine to detect darkened seeds, and treatment with fungicides, the treated rice seeds are placed in over 250,000 packets and sent to more than 80 countries in the International Rice Testing Program (IRTP) every year.

New techniques in biotechnology and serology are greatly facilitating the task of preparing disease-free germplasm, particularly for vegetatively propagated crops. Meristem culture, DNA probes, and recently developed serological tests reduce the amount of growing out required and can be used to screen rapidly large quantities of germplasm. These tools are well within the reach of developing countries since many techniques in biotechnology and serology are relatively inexpensive and can be learned readily.

Antisera production is expanding rapidly for use in detecting a broad range of pathogens, particularly viruses and bacteria. New applications are constantly being found. CIP, based in Lima, Peru, has recently developed antisera against races 1,2, and 3 of bacterial wilt (*Pseudomonas solanacearum*), a widespread potato disease. These antisera do not require germplasm to be in tissue culture form, thus they can be used more widely in detection work. CIP has prepared kits which have been distributed to regional scientists, and the demand for the kits is expected to be strong. CIP has helped Peru, Brazil, Colombia, and Tunisia produce antisera for screening potato germplasm (CIP, 1984:8).

Simplified serological techniques developed by CIP scientists have enabled some developing countries to use ultrasensitive methods to detect viral and viroid pathogens of potato. ELISA (enzyme-linked immunosorbent assay), for example, was perfected in 1977 for detecting viruses and adopted at CIP the same year. CIP scientists have developed ELISA kits that can be used in the field to detect potato leaf roll virus (PLRV) and potato virus Y (PVY). The kit costs $250 and has been adopted in 13 developing countries (CIP, 1984:64).

Other agricultural research centers use ELISA to screen germplasm of many plant species for viruses. The Asian Vegetable Research and Development Center (AVRDC) in Taiwan employs ELISA to index meristem-derived sweet potato (Ipomoea batatas) plantlets destined for germplasm exchange for the presence of SPV-A, SPV-N, feathery mottle virus, sweetpotato latent virus, sweetpotato yellow dwarf virus, and sweetpotato mild mottle virus, all viral pathogens (AVRDC, 1985:26; 1987). And at ICRISAT, technicians use an ELISA kit to verify that groundnut germplasm is free of peanut stripe virus and peanut mottle virus.

Tissue culture techniques are making it increasingly less risky to ship root and tuber crop germplasm, so tissue culture is rapidly becoming the preferred method for exchanging clonal material (Withers, 1982). Tissue culture is now routinely used to export germplasm of potato, sweet potato, cassava (Manihot esculenta), yams (Dioscorea spp.), and some cultivars of banana. A major reason for this development is that tissue culture procedures, used in conjunction with thermotherapy, produce apparently disease-free germplasm.

Freeing plants of viruses usually begins with removal of shoot tips from healthy-looking plants, since rapidly dividing cells have less chance of being invaded by viruses. Heat treatment and disease indexing further reduce the chances of viral infection before clonal germplasm is ready for shipment. It should be remembered, though, that DNA probes and other diagnostic procedures can only detect those specific pathogens and pathotypes they are designed to screen for.

CIP routinely tests potato germplasm in tissue culture for certain diseases. CIP and most national programs with which the center collaborates use a pathogen-elimination system of thermotherapy of whole plants at 36 C for four to six weeks followed by meristem culture (CIP, 1987). After indexing for pathogens, meristem-derived material is used for storage, tuber production, or shipment (Figure 5). CIP provides this "clean up" service for several national potato programs. Scientists at the center use electrophoresis and a DNA probe to screen potato tissue for the potato spindle tuber viroid (PSTV) (Figure 6). Other techniques used to screen germplasm for viruses include serology (ELISA and antibody-sensitized latex particles) and electron microscopy. Using such techniques, CIP sent pathogen-tested potato germplasm to 53 developing countries and 17 industrial nations in 1983 (CIP, 1984:64). In collaboration with Stephen Slack of the University of Wisconsin, CIP is developing in vitro methods of thermotherapy and chemotherapy. When perfected, these procedures promise to trim considerably the time required to screen potato germplasm for pathogens.

Figure 5. Use of the pathogen-tested potato collection at the International Potato Center (CIP--Centro Internacional de La Papa), Lima, Peru.

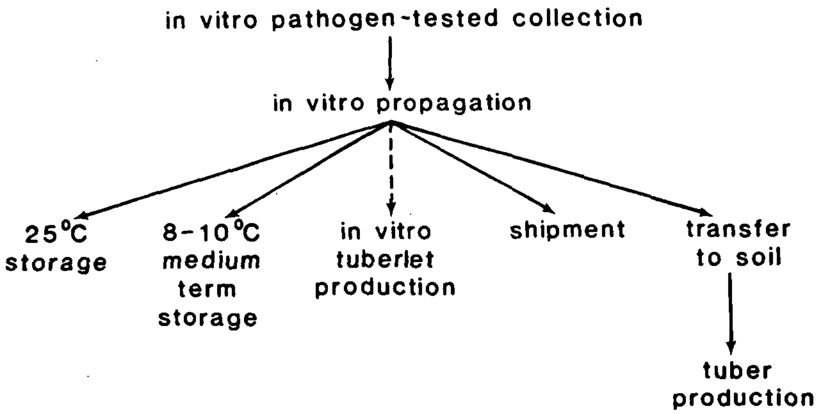
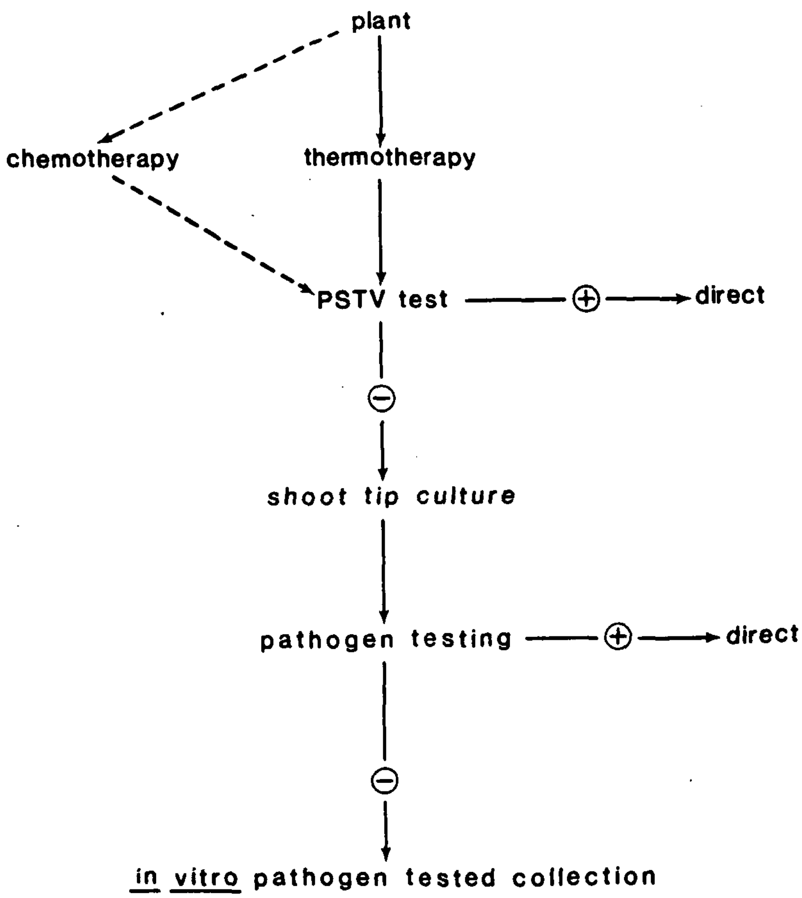


Figure 6. Cleaning-up procedure for potato destined for germplasm storage or exchange at the International Potato Center (CIP--Centro Internacional de La Papa), Lima, Peru. A plus sign signifies pathogen detected.



CIAT employs tissue culture to exchange and store cassava germplasm. Stakes are first cut from robust cassava plants and planted in a glasshouse to see if any latent diseases emerge. Duplicate stakes are placed in a heat chamber at 40 C during the day and 35 C at night for three weeks. Elevated temperatures apparently slow the replication of viruses. Shoot tips are taken from heat-treated cassava stakes and are cultured to produce plantlets. After a month's growth, the plantlets are divided into single-node cuttings and follow-up serological tests are performed to check for viruses (IBPGR, 1983:3). From 1978 to 1984, CIAT received 1,588 cassava accessions in tissue culture form from various germplasm collections (CIAT, 1985a:39).

AVRDC, CIAT, CIP, IITA, and other agricultural research centers also employ tissue culture to distribute advanced breeding lines of root crops around the world. Between 1981 and 1986, IITA sent over 14,000 tissue cultures of sweet potato to 34 African countries and 26 nations outside the continent (Ng, 1987). By 1987, IITA had 33 improved sweet potato varieties approved by the Nigerian quarantine service in cleaned-up tissue culture form and available for distribution to interested parties. As of early 1985, CIAT had sent 50 elite cassava varieties to various countries in Latin America and Southeast Asia (CIAT, 1985a:39). Tissue culture has also allowed the importation of cassava germplasm into Malaysia from all regions except Africa and the Indian subcontinent (T. S. Lian, pers. comm.). An additional advantage of exchanging clonal germplasm in tissue culture form is that it is lighter and thus cheaper to ship by air freight than cuttings or tubers. Another benefit is the generally increased yield of cassava plants grown from tissue culture, probably because they are freer of diseases (CIAT, 1984).

Tissue culture is used primarily to clean up and ship clonal materials, but the technique is also sometimes used for plants that normally are reproduced from true seed. The Addis Ababa-based International Livestock Center for Africa (ILCA), for example, ships some grass forage germplasm as tissue cultures to reduce the chances of spreading diseases.

Although tissue culture and new disease indexing methods are making it easier to clean up germplasm for shipment, some problems remain. Micropropagation can actually accelerate the spread of diseases, as in the case of the orchid industry, unless tissue cultures have been carefully screened for pathogens (Hartman and Zettler, 1986). CIP now has the capability to screen potato germplasm for 25 viruses using ELISA and other techniques, but APHIS in the U.S.A. does not recognize fully CIP's procedures. Potato material, either in tissue culture or seed potato form, imported into the United States from CIP still must be observed through two growing cycles before it can be released to breeders. Also, ELISA can only be developed to detect a virus if the virus, and any pathotypes, have been adequately characterized. Only in 1987, for example, was an ELISA test developed for cocoa swollen shoot virus, a major problem in Ghana's cacao plantations (L.H. Purdy, pers. comm.). It is not yet clear, though, whether there is more than one strain of cocoa swollen shoot virus.

Some countries lack adequate facilities for handling germplasm shipments in the form of tissue cultures. To overcome this problem, AVRDC scientists prepare small, virus-free storage roots of sweet potato for shipment to breeders in the following manner: virus-free plantlets derived from conventional shoot-tip culture are transplanted in a sterile soil and grown in an insect-free environment. Leaves from mature plants are cut at the base of the leaf stem (petiole) and planted in freshly sterilized soil until they develop roots. Leaves of plants with storage roots are given an ELISA assay before the roots are cleared for shipment (AVRDC, 1984). In 1985, AVRDC distributed 13,000 small, virus-free roots compared with only 130 tissue culture shipments in 1983.

Quarantine services use many of the same techniques as scientists in preparing germplasm for export. Quarantine operations, particularly in the developed countries, routinely use serological tests and electron microscopy to detect viruses. Prohibited or restricted materials suspected of harboring a pathogen may be grafted to known susceptible plants, or sap taken from quarantined materials can be mechanically transmitted to vulnerable indicator plants.

VII. INTERMEDIATE QUARANTINE

A major tool in quarantine work is the use of intermediate quarantine stations where material is generally observed far from areas in which the crop is grown. Sugarcane (Saccharum spp.) germplasm destined for the Hawaiian Sugar Planters' Association, for example, is quarantined in the state of Maryland. Formerly, sugarcane germplasm for breeding programs in Hawaii was checked first at a quarantine station on Molokai, a Hawaiian island with no sugarcane plantations. But this operation was shifted to Maryland for safety reasons; the nearest sugarcane plantation to the Beltsville Station is over 1,600 kilometers away. India plans to establish an intermediate quarantine station for coconut (Cocos nucifera) germplasm on the Lakshadweep Islands off the southwest coast of India near the Maldive Islands.

Countries that do not have plant quarantine stations isolated from crop growing areas sometimes use a third country as a holding area. Such quarantine bridges have been used for decades. In the 1920s, the United Fruit Company used Utila, an island off the northern coast of Honduras, as a way-station to bring banana germplasm to its Lancetilla Experiment Station near Tela, Honduras (Dunlap, 1967).

Several industrial countries currently provide intermediate quarantine services for certain tropical crops. The Institute for Research on Cacao and Coffee (IRCC) at Montpellier, France, provides intermediate quarantine for a limited amount of coffee germplasm, and plans to do the same for cacao in the future. The Subtropical Horticulture Research Station in Miami, Florida, is currently the only widely-recognized intermediate quarantine facility for cacao in the world. The Subtropical Horticulture Research Station uses two greenhouses for checking cacao shipments for pathogens and maintains a germplasm collection of 320 accessions. Station personnel screen cacao materials for diseases by grafting on susceptible plants since no virologist is on staff to use more sophisticated indexing methods. This USDA station provides intermediate quarantine at no charge for cacao and avocado germplasm for any institution requesting such service; thus far, most requests for processing cacao have come from Latin America, Malaysia, Papua New Guinea, and Western Samoa. Until IRCC in France adds its own capability for quarantining cacao germplasm, the London-based Cocoa Chocolate and Confectionary Alliance has arranged for Reading University in England to begin in 1987 a temporary quarantine service for cacao (E. T. Beauchamp, pers. comm.). The former Plant Introduction Station in Glenn Dale, Maryland, has quarantined coffee on behalf of several countries since the 1950s (Rodrigues, 1977). The Royal Botanic Gardens, Kew, examines and repackages samples of cassava seed destined for Malaysia. CIP uses quarantine services in Australia and the

Netherlands to facilitate the exchange of potato germplasm, and ICRISAT has worked out an agreement with Reading University to act as a quarantine way-station for vegetative material of wild groundnuts.

The future of some intermediate quarantine services is in doubt at present because of declining budgets in industrial countries that provide such assistance for developing countries. In most cases, quarantine services have been operated by institutions in developed countries to assist former colonies or developing countries with which the supporting country has special relationships. Funds have often been provided from foreign assistance budgets; in many cases, though, such funds have been severely cut back or even eliminated, thereby jeopardizing many intermediate quarantine services. Furthermore, this discouraging downward trend in funding for intermediate quarantine comes at a time when the demand for such facilities is greater than ever.

VIII. FUTURE TASKS

Plant quarantine needs more attention if it is to continue to provide essential services. Better facilities, more precise detection methods, additional well-trained staff, and more research are required to upgrade quarantine work worldwide. More contact--even a partnership relationship--between quarantine officers and plant scientists who are the users and providers of many of the materials of concern are also needed to improve the effectiveness of quarantine services. In this closing section we will discuss some of the future needs of quarantine services and suggest some possible approaches for improvement.

Demand for intermediate plant quarantine is sufficiently strong to warrant establishing more such operations. The need for intermediate quarantine facilities is particularly acute for tropical export crops since several industrial countries have dropped such services. In 1981, the Subtropical Horticulture Research Station at Miami stopped quarantining coffee germplasm when the U.S. Agency for International Development withdrew its annual contribution of $70,000 for the service (R.J. Knight, Jr., pers. comm.). This facility had been serving the coffee germplasm needs of as many as 15 countries, particularly the regional genebank at the Centro Agronomico Tropical de Investigacion y Ensenanza (CATIE), Turrialba, Costa Rica. The Netherlands, the United Kingdom, and Portugal have largely pulled out of intermediate quarantine for tropical cash crops due to cost considerations and because they no longer administer colonial empires. The Royal Botanic Gardens, Kew, phased out intermediate quarantine for banana in the late 1960s, and did the same for sugarcane and cacao in 1981 and 1984, respectively (A.G. Bailey, pers. comm.). The Royal Tropical Institute in Amsterdam ceased intermediate quarantine work on cacao and African oil palm in the early 1970s (J. Hardon, pers. comm.). The Center for Coffee Rust Research (CIFC--Centro de Investigacao das Ferrugens do Cafeeiro) at Oeiras, Portugal, stopped providing quarantine service for coffee germplasm destined for former Portuguese colonies several years ago (C.J. Rodrigues, pers. comm.).

A pressing need has arisen for more intermediate quarantine facilities for coffee, cacao, sugarcane, coconut, cassava, and cashew (*Anacardium occidentale*) (Gregory, 1977; Harries, 1977; Ohler, 1977; Karpati, 1981). The crux of the problem here is funding. Former colonial powers no longer feel obliged to provide a free service to tropical territories that have since become independent nations. The foreign assistance regulations of most industrial countries stipulate that development assistance funds must be spent in developing nations, yet this is about the only source of funding for intermediate quarantine facilities which are usually in developed countries. Universities, botanic gardens, and agricultural research institutes in temperate countries therefore experience difficulties in obtaining funds from their own governments for intermediate quarantine work on crops of little direct importance to the country. In the case of the Research Institute for Plant Protection at Wageningen in the Netherlands, for example, scientists are eager to do more cleaning up of cassava germplasm shipments for IITA in Nigeria, but funding sources are uncertain.

Support for intermediate quarantine for developing countries will probably have to come from a consortium of donors including governments in the Third World, organizations representing commodity and consumer groups, and bilateral and multilateral aid organizations. The Washington, D.C.-based American Cocoa Research Institute and a consortium of European donors, for example, provide some funds for intermediate quarantine for cacao at the Subtropical Horticulture Research Station in Miami.

Intermediate quarantine facilities have historically been concentrated in industrial countries where facilities and expertise are better developed and climatic conditions are not conducive to the spread of tropical pathogens and arthropods. But in addition to revitalizing the role of temperate countries in intermediate quarantine, similar facilities need to be improved and added in the tropics and sub-tropics. The University of the West Indies in Barbados provides a limited quarantine service for cacao germplasm destined for the cacao genebank on Trinidad, but other countries are not fully satisfied that materials leaving the genebank are free of pathogens. The major concern here is that cacao germplasm may be contaminated with cocoa swollen shoot virus which is thus far confined to Ghana, Togo, and the Ivory Coast. The intermediate quarantine service for cacao operated by the University of West Indies for the Caribbean region would undoubtedly benefit from increased financial support so that it could upgrade and expand its work, especially in virus detection and cleanup.

To facilitate the introduction of plant germplasm to Latin America, Navarrete (1967) proposed establishing three or four plant introduction centers in the region under the auspices of the Organization of American States. OIRSA, a regional quarantine organization for Central America (Table A.1) is considering the establishment of intermediate quarantine facilities to serve its seven member countries.

Temperate countries would also benefit from more intermediate quarantine and disease indexing services, especially for fruit crops. Funds are needed to organize periodic monitoring tours and workshops for quarantine officers and seed health specialists so that methodologies can be up-dated and standardized and quarantine officers appraised of developments in capabilities of other quarantine operations.

In most countries, including industrial ones, quarantine services would benefit from better facilities and more trained personnel (Berg, 1977; Chiarappa and Karpati, 1984; Neergaard, 1984). Nigeria is the only country with any quarantine facilities in the vast area stretching from West to Central Africa (Chiarappa, 1985). Some national plant quarantine agencies operate more on a basis of authority than science (Adamson, 1941; Mathys, 1977). Madagascar has only one quarantine officer and two assistants trained in plant pathology (ISNAR, 1983:119). Even Brazil, which has a relatively well developed agricultural research program, has only seven scientists in Brasilia to handle quarantine operations for the entire country. Nematology (Figure 7) and virology are two particularly weak areas in many quarantine services. Another major weakness of many quarantine services is an inability to handle and process germplasm in tissue culture form.

Figure 7. A state quarantine officer in Honolulu, Hawaii, checking root masses of imported germplasm for nematodes, 1986.

Many quarantine services could be upgraded with minimal additional investment by decentralizing operations and by forging better links with local universities and agricultural research centers. In this manner existing expertise can be pooled more readily and delays in the processing of material can be reduced. Some Brazilian scientists believe Brazil's quarantine service could be streamlined if researchers working with individual crops were allowed to quarantine imported material for their crops. If quarantine services are to be consolidated at a single location, arrangements with scientists at research institutions elsewhere in the country would facilitate the task of screening incoming material. Thailand's quarantine service, for example, relies heavily on the services of a virologist and a nematologist at Kasetsart University in Bangkok.

Most Third World quarantine services would benefit from better facilities and a reliable source of supplies. International centers, or some international funding agency or a consortium of donors, should be prepared to help national quarantine services whenever possible because of the greater workload brought on by a broadened international agricultural research system. Several international agricultural research centers have helped national quarantine services with supplies, equipment and training. Such positive steps should be encouraged. The amount of support needed to upgrade Third World quarantine services is modest compared to the value of a smoother, and safer, exchange of crop materials. The Muguga quarantine station in Kenya, for example, needs a deep well to assure a good quality water supply for laboratory work and for watering plants; such an investment, which could ultimately benefit several nations, is hardly likely to dent the external aid budget of any industrial country or private foundation.

Nearly all quarantine services in the Third World are understaffed, and increased training opportunities are urgently needed. Thailand's quarantine service does a commendable job considering that it had only one Ph.D and 4 M.Sc. staff members as of June 1986; work would be greatly facilitated with more well-trained scientists. In some Third World countries, the ever-increasing volume of international germplasm shipments severely taxes the already understaffed and inadequately equipped quarantine services. This problem is particularly acute for nations hosting international agricultural research centers, since they receive large germplasm shipments--both incoming and outgoing-- for diverse breeding programs and sizeable center genebanks. For example, IITA accounts for over two-thirds of the workload of Nigeria's quarantine service (Aluko, 1982). International centers and donors may need to consider increasing their support for national quarantine services to relieve some of the burden of germplasm destined for genebank collections and multilocation testing.

Several international, regional, and national organizations have stepped in to try and fill the quarantine manpower gap in developing nations. FAO has operated two to three training courses in plant quarantine per year over the last 15 years. PLANTI near Kuala Lumpur offers a diploma in plant quarantine after 10 months of in-residence study, and a certificate in plant quarantine after five months of study. Furthermore, PLANTI annually offers 14 courses, lasting from one to three weeks, that cover a wide range of quarantine activities[5]. In 1987, PLANTI launched a two-year Master of Science degree program in collaboration with Universiti Kebangsaan Malaysia (PLANTI, 1987).

International agricultural research centers and some institutions in industrial nations are helping to upgrade quarantine services through their various course offerings. CIP, for example, trains tissue culture specialists, and now 16 countries are able to handle potato germplasm shipments in tissue culture form. Between 1978 and 1983, CIP trained 188 scientists from 56 countries in germplasm management (CIP, 1984:10, 50). CIAT has offered an advanced course on seed quality and disease control since 1985. In its inaugural year, the advanced seed course was offered with the assistance of several U.S. universities, the head of the Seed Testing Laboratory in Brisbane, Australia, and Colombian scientists and seedsmen. The course served 29 people in 1985: 9 from crop research institutes, 4 from universities, and 16 from the seed sector (CIAT, 1985b:2). Some plant quarantine officers in developing countries receive training in plant pathology in Australia and at the APHIS facility in Frederick, Maryland. The Danish International Development Agency (DANIDA) funds the Danish Government Institute of Seed Pathology for Developing Countries in Copenhagen which was set up specifically to train Third World specialists in seed pathology. As of October 1985, this exemplary institute, which was established in 1967, had trained 350 people from the Third World (Neergaard, 1986). The Institute's basic course lasts half a year and is followed by a further six months of research.

Information about crop pests and diseases should be more readily available, particularly in the Third World where access to good quality libraries is limited. Quarantine services are beginning to use microcomputers to tap into databases containing up-to-date information about the distribution of crop pests and pathogens, and this trend warrants support. Computer networks can be set up to post bulletins alerting quarantine officers about genetic shifts in pathogens and recent outbreaks of diseases and pests (IRRI, 1984:9). The USDA's Agricultural Research Service is establishing a world database on plant pathogens at Frederick, Maryland. This database will contain information on the known distribution of crop pests and pathogens, symptoms of infestation, and the potential for increased virulence. Such databases deserve full financial and institutional support, especially when the collated information is widely shared.

Databases and other electronic means of disseminating information can never substitute, however, for occasional face-to-face meetings of scientists and quarantine officers. Indeed, workshops for plant breeders, genebank curators, and quarantine officers are rare. Such meetings could iron out some of the differences between plant breeding operations and quarantine services. Again, international organizations can play a key role in hosting and partially funding such encounters.

Crop breeding programs worldwide would benefit from a mechanism for a second hearing on the fate of germplasm considered as borderline cases for introduction by plant quarantine officers. Instead of summarily destroying or refusing entry to all questionable plant materials, quarantine services might seek the advice of outside review panels composed of distinguished scientists. Such outside advisory bodies would only be approached if the germplasm in question seemed to be of sufficient potential value to warrant a stay of execution. The composition of the advisory body would be a delicate issue. In addition to plant breeders, university scientists specializing in plant pathology, entomology, nematology, and economic botany, for example, would be potential members of such quarantine review panels. Whatever the mix of specialties on the advisory body, one quality is essential: the ability to act quickly.

New and emerging technologies for detecting pathogens will undoubtedly facilitate the work of quarantine officers in the future. Research into tissue culture techniques and the use of monoclonal antibodies and other advanced diagnostic tools for detecting pathogens warrants further support. In 1986, monoclonal antibodies in diagnostic work had become a $130 million business; by 1990, monoclonal antibodies are expected to be a $2 billion a year industry (Young, 1986). A type of stethoscope that can pick up sounds made by insects as they feed on fruit and grains is being tested at a USDA laboratory in Gainesville, Florida[6]. A similar device has been developed by scientists at Purdue University in Lafayette, Indiana, U.S.A.

Sophisticated X-ray machines now in use at some airports are capable of detecting fruit in luggage and thus can be used to intercept some vegetative materials that might be carrying pests or pathogens. APHIS officials in Puerto Rico have successfully used X-rays to screen baggage of passengers boarding flights to the United States. In Hawaii, APHIS personnel visually inspect luggage destined for the mainland, even though X-rays are more efficient and a less expensive means of accomplishing the task. APHIS has started using Beagle dogs to sniff out agricultural products in international baggage at airports in San Francisco, Los Angeles, Miami, Seattle, and New York. More U.S. airports are soon expected to be served by these canine detectors[7].

One area of plant health that requires particular attention is cleaning up germplasm collections in dozens of genebanks worldwide. Work on such a monumental task has barely begun, mainly because of cost considerations. Many germplasm collections were assembled before quarantine operations came into effect or diagnostic tools were available for detecting certain pathogens. This applies particularly to viruses. True, many important plant viral diseases are now widespread, but that is no excuse for ignoring the dangers of shipping infected materials. Certain pathotypes of viruses, fungi, or bacteria may be absent from areas where more benign forms are present; if these new pathotypes are introduced in breeding materials, serious crop damage may result.

Clean up of germplasm collections could be accomplished gradually as acquisitions are evaluated for useful genes, or when seed accessions are regenerated to ensure their viability. Disease indexing at such times will increase costs, but it will be cheaper than attempting clean up alone. Some difficult questions will confront germplasm curators, such as whether it is feasible to eliminate all detected pathogens and how to rank diseases in order of importance. One technique used in reducing chances of passing on infected material needs careful consideration in genebanks. Selection of only a few healthy-looking plants from an accession containing tens of thousands of seeds to serve as the founding seed stock could result in the loss of some potentially valuable genes.

Clean up of accessions of vegetatively-propagated material poses more difficult problems. If disease-indexed accessions are planted in field genebanks, they may become re-infected with at least some pathogens, depending on the location and operations of the genebank. In such cases, clean up may only be feasible when germplasm is being readied for shipment to another location.

More basic research on the biology and life cycles of crop pests and pathogens would also benefit quarantine work (Rohrbach, 1983; Reddy, 1984; Curtis, 1985). Knowledge of the etiology and accurate diagnosis of several virus-like crop diseases is still fragmentary (IBPGR, 1982). Pests and pathogens of forage species are poorly understood, so it is difficult to assess the risks involved in the exchange of forage and pasture plants. A similar problem exists with the more than 400 fungi associated with African oil palm, most of which have only been described (Turner, 1977b). The work of C. J. Rodrigues and his colleagues at the Center for the Study of Coffee Rust (CIFC) in Oeiras, Portugal, is exemplary in tenaciously pursuing research on the biology and ecology of that important crop pathogen. CIFC has thus far identified 33 races of coffee rust; these are maintained in a laboratory collection[8].

A better understanding of the natural history of damaging insects, bacteria, viruses, fungi, and nematodes is clearly essential to improve quarantine work worldwide

(Harding, 1947:78). The range of alternate hosts of important crop pathogens and pests particularly needs elucidation. Some viruses, for example, infect a wide range of plants, and quarantine efforts focused exclusively on imported germplasm of the vulnerable crop will probably be of little avail if alternate hosts carrying the virus are allowed in without screening. Sweet potato viruses infect several plant species belonging to different genera and even families (Terry, 1974). Some 150 plant species in 22 families have been found naturally contaminated with alfalfa mosaic virus, and broad bean wilt virus attacks 67 plant species in 27 families (Bos, 1981). Tobacco ringspot virus, the causative agent of budblight disease of soybean, infects a wide range of dicotyledonous plants (Gerlach et al., 1987). The causal agent (*Sphaceloma* sp.) of superelongation disease of cassava has been discovered on *Poinsettia*, an important ornamental in the nursery trade around the world (Lozano, 1977). Research has shown that the strain of flag smut found on wheat in the United States differs little, if any, from flag smut reported elsewhere; this pathogen may thus warrant a lower ranking in terms of importation risk. Studies of the life cycles of pests and pathogens reveal what forms they adopt at different stages in their lives and which treatments are appropriate. Many viruses are transmitted by arthropods and nematodes, and when vectors are identified they can also be placed on the danger lists.

The life history and impact of a pest or pathogen must be studied at more than one location in its range. Behavior of an insect or pathogen in just one country is not a reliable indicator of its danger for another nation. A minor pest or disease in one region can cause serious damage elsewhere. Maize rust, caused by *Puccinia polysora*, is not economically important in tropical America, but is a serious problem in maize fields in Africa, where it was first detected in Sierra Leone in 1949, and in Asia (Karpati, 1983). Of the 212 economically important immigrant insects and mites in the United States, only 73 are considered significant pests in their countries of origin (Mathys and Baker, 1980). Cold winters or severe dry seasons can dampen the effect of introduced pests; such information helps quarantine officers when they categorize pests according to their potential danger.

The United States has a particularly important leadership role in quarantine work. Several countries follow decisions adopted by APHIS, so it is especially important that the U.S. quarantine service be equipped with the latest information and superior facilities. Unfortunately, as the workload increases for APHIS, budget cuts loom on the horizon. The overall 1988 budget for APHIS has been trimmed by $6.6 million to $303.3 million (Tangley, 1987). True, APHIS is to be upgraded with a new biotechnology initiative, but most of the proposed capacity will be geared to overseeing the growing list of regulations governing the release of genetically engineered agricultural products rather than screening incoming germplasm.

The global quarantine system is becoming ever more integrated, with considerable sharing of information and technologies. Translating research results into tangible benefits for farmers and consumers is a multi-step process, involving many key players in the system. Quarantine is an important link in that chain, and it needs to be strengthened.

NOTES

1. Pests include arthropods such as insects and mites, while pathogens refer to micro-organisms, such as viruses, viroids, bacteria, and fungi, that trigger diseases.

2. Economist 30(7472):90 (15 November 1986).

3. Gainesville Sun, Gainesville, Florida, 31 January 1986, p. 2C.

4. Nature 324:331 (1986).

5. PLANTI offered the following training courses in 1987: Fumigation for Operators; Human Resource Management; Plant Quarantine Treatments; Identification of Major Diseases of Economic Crops; Documentation and Information System for Plant Quarantine; Nematodes in Consignments; Pests of Fruits; Container Inspection and Treatment; Workshop for Agencies Involved with Plant Quarantine Services (covering such topics as customs and immigration); Safe Use of Pesticides; Weed Contaminants in Seed Consignments; Storage Pests; Viruses in Ornamentals; and Techniques for Preserving Organisms.

6. Time, 8 September 1986, p. 69.

7. Going Places (American Automobile Association) 6(4):35, July-August.

8. Nature 324:331 (1986).

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