The Role of FAO in Research and Control

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Dead and dying coconut palms with cadang-cadang disease in the Philippines.

The Food and Agriculture Organization of the United Nations (FAO), an autonomous intergovernmental agency dealing with agricultural development, was established in 1945 at Quebec, Canada. Objectives were to 1) raise levels of nutrition and standards of living throughout the world, 2) increase efficiency in the production and distribution of food and agricultural products, and 3) improve living conditions of rural populations.

To achieve these goals over the years, FAO has extended its activities to an increasingly larger number of fields, including the area of plant disease research and control. The involvement of FAO in research and control has never been free of serious obstacles and constraints arising from difficult and often complex national and international situations. This should be noted not only to appreciate the achievements obtained under these conditions but also to give credit to the many plant pathologists who have contributed over the years to FAO programs.

Structure and Operation

FAO has a current membership of 144 countries, more than three times the number when founded. The contribution of each country to the approved budget for FAO's regular program is based on its gross national product. The budget for the 1978–1979 biennium was \$211.3 million. Additional funds for the operation of FAO's field programs are derived either from the United Nations Development Programme (which in turn receives appropriations from the United Nations Economic and Social Council) or from bilateral and other sources. Additional funds for the 1978–1979 biennium amounted to approximately \$500 million.

With these funds, FAO provides technical assistance to requesting member governments, mostly in the form of clearly defined term projects. In 1978, a total of 1,500 projects with a value of over \$800 million were either approved or operational in 132 countries. These projects cover nearly all aspects of development in agriculture, nutrition,

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forestry, and fisheries and usually involve provision of internationally recruited experts, granting of fellowships, and supply of equipment and materials. One condition for approving these projects is that governments requesting aid must provide local facilities and personnel. FAO projects in plant pathology have been many and varied over the years (3,4).

Important Plant Diseases in Member Countries

The great majority of plant diseases in which FAO has played a role in both research and control have been of considerable socioeconomic importance. Local governments have called for outside assistance because a disease had reached a stage of development difficult to control or because the problems were complex and difficult to solve. A few examples of these situations follow.

The "unknown diseases" of coconut. In the tropics, the coconut palm (*Cocos nucifera* L.) is called the "tree of heaven" because of its unique capacity to provide millions of people with food, drink, shelter, timber, and fuel. The coconut palm is typically a small holder's crop requiring a minimum of care and managerial skills. In addition, the tree is long-lived and grows where crops often cannot survive.

Approximately 6 million ha of coconuts are grown in FAO member countries, with the Philippines being the world's largest single producer (about 2.5 million tons of copra). World coconut production is seriously threatened by two diseases, both of great socioeconomic importance because of the large stratum of population affected and the difficulty in finding replacement crops. One of these diseases, at present confined to the Philippines, is known as cadang-cadang. The other, lethal yellowing, is distributed in West Africa, the Caribbean, and Florida and is known by different names.

Cadang-cadang. This disease was first observed in the Philippines on the island of San Miguel southeast of Luzon in 1933 (12). Initially, it spread southeastward and by 1962 had destroyed 250,000 coconut palms, leaving only 80 surviving trees. Later, cadang-cadang moved to other provinces, causing losses estimated at 20 million trees. The disease still poses a serious threat to the economy of the entire country, which depends heavily on copra for earning foreign currency. In addition, an estimated 8 million people, more than one-third of the entire population, could be seriously affected if the disease should continue to spread and become generally established in the Philippines.

When FAO assistance was first requested in 1955, several possible causes of the disease had already been suggested, including volcanic eruptions, typhoon damage, radioactive fallout, nutritional deficiencies or toxicities, and viruses. Serious administrative and infrastructural difficulties limited research capability, which was almost entirely confined to an isolated and poorly equipped research station. This situation called for a long-term effort on the part of the local government and FAO and for continuous readjustments in the research program.

Lethal yellowing. Considered one of the most devastating diseases of perennial crops, lethal yellowing can kill mature palms in 2–3 mo and in Jamaica moved rapidly over areas of susceptible trees, killing 60,000–100,000 palms a year.

As a result of devastation in West Africa, mainly Ghana and Togo, a large number of fishing villages along the coast were abandoned; living was no longer possible for local populations who derived essential food, drink, and shelter from coconut palms. The global threat posed by lethal yellowing disease has

Aerial view of coconut palms with lethal yellowing in Jamaica.

Coffee berry disease, with blackening of berries, on a susceptible coffee cultivar in Kenya.

been estimated recently by Harries (8) to represent a potential loss of 62% of the world's total coconut production. Clearly, this disease is of great socio-economic significance and will require considerable international effort to control. Yet, until the disease reached Florida in 1972, only a handful of scientists were involved in seeking control measures. They were working primarily in Jamaica, where FAO provided assistance from 1962 to 1975.

Destructive diseases of coffee. Two such diseases—coffee berry disease (CBD) and coffee leaf rust—exist in areas of the world where serious social and economic constraints offer little amplitude for solution.

Coffee berry disease. This disease is caused by the fungus *Colletotrichum coffeanum* Noack, which exists in different pathogenic forms. The CBD form, accidentally introduced into Ethiopia in the late 1960s, causes typical anthracnose of green berries and total loss of the crop (20). CBD spread quite rapidly in the western and southwestern provinces of Ethiopia and in 1978 was also reported in the Harrage region. The loss caused by the disease is now estimated at nearly 30% of the total coffee production. This estimate is based on the average of actual coffee deliveries in the central market of Addis Ababa during the 4-yr periods immediately preceding and following CBD spread and establishment in the country.

Chemical control of CBD, as successfully practiced in Kenya, could not be used in Ethiopia to reduce these losses for two reasons. First, in Kenya coffee is grown under conditions of modern technology based on high inputs/high outputs, whereas in Ethiopia most of the coffee is cropped by traditional farmers who possess neither the finances nor the technology to engage in chemical control. Second, most of the crop in Ethiopia is grown as "forest" coffee, with crowded plants left unpruned and difficult to spray. As a result, only 10% of the total coffee acreage in Ethiopia is considered suitable to chemical control.

Coffee leaf rust. Up to 1970 the Western Hemisphere had remained free of coffee leaf rust, caused by *Hemileia vastatrix* Berk. & Br. In 1970 the fungus was found in Bahia and from there spread throughout Brazil, Argentina, and Paraguay. In 1975 an independent outbreak occurred in Nicaragua; the disease was found in Peru in 1978 and in Bolivia in 1979. There is concern that the disease will spread to other countries in South and Central America where small coffee holders prevail and where much socioeconomic distress is likely. This is true in Colombia and many other countries still free of the disease where coffee is grown on small estates, often in locations where spraying with fungicides is not technically and economically feasible.

The new wheat disease situation in Latin America. Because of expansion of wheat growing in South America, an entirely new epidemiologic situation has developed favoring the periodic occurrence of devastating disease outbreaks. Wheat is cultivated as far north as Petrolina in Brazil (10° S), and an aerial "path" of rust spores has been artificially created resembling that existing between Mexico and Canada. Rust epidemics begin in the northern part of Brazil and extend exponentially southward with the advancing season. The traditional control of rust diseases by the use of vertical resistance genes in wheat cultivars is no longer adequate, and the average commercial life of a new wheat cultivar is about 2 yr. Lately, this problem has worsened with the appearance in South America of European aphids that vector the barley yellow dwarf (BYD) virus. All South American cultivars have shown high susceptibility to the wheat-aphid complex, and reductions in yield vary from 50 to 90%. In 1977 a demonstration of the new epidemiologic situation created in South America was clearly seen in Brazil. In the state of Rio Grande do Sul, which is the largest wheat producer with 1.573 million ha, a combination of rusts, *Septoria* infection, BYD, and aphids caused an overall loss estimated at 63% of the average production. With the newly created wheat-parasite problem in Latin America, individual national efforts were no longer sufficient. Other approaches were urgently needed.

International Assistance in Plant Pathology

The described diseases occur as major epidemics and have a spectacular appearance that forces local governments to "do something." In addition to these emergency requests, FAO receives many different calls from member governments that are then reflected in FAO's work in research and control of plant diseases. Some of these activities concern the study and control of less spectacular diseases; ad hoc advice on certain plant disease problems; establishment of national infrastructures, such as research institutes, laboratories in experiment stations, and disease warning/monitoring systems; provision of equipment and material, such as vehicles, sprayers, and fungicides; and, most important, the training component.

After nearly 30 yr of such work, it is rewarding to see that the fruits of this more "silent" assistance are being produced and that in most FAO countries a core of plant pathologists is active and ready to assume increasingly larger responsibilities. This will undoubtedly determine a shift in international assistance that must adjust and harmonize with the new developments.

Approaches to Research Methods

Although FAO is not a research organization, agricultural research is regarded as an important input in the development process. To be fully effective, this input must be perfectly integrated with all other development efforts and be directed toward solving clearly defined problems. To produce the desired effects within a reasonable time, research must have practical significance and always remain linked to the ultimate users: the farmers.

When possible, new ideas or entirely innovative research methodologies are encouraged by FAO in member countries where there is clear indication that their application might produce further advances in crop protection and production. This leading role in research is taken by FAO when research must be tailored to the individual requirements of a country or when other research approaches and conventional methodologies have not succeeded.

The "unknown diseases" of coconut. FAO involvement in research on the etiology of cadang-cadang and lethal yellowing started many years before the discovery of viroids and mycoplasmas as causal agents of plant diseases.

Cadang-cadang. The first expert assigned to investigate cadang-cadang in the Philippines was R. S. Vasudeva from India, who served in the country in 1955. He was followed by a number of internationally known plant virologists, including W. C. Price (1957 and 1971–1973), F. P. McWhorter (1959), K. Maramorosch (1960), F. O. Holmes (1961–1962), W. H. Sill, Jr. (1962–1963), and A. N. Nagaraj (1963–1967). Research was also done on possible insect vectors by E. S. Sylvester (1974–1975) and on disease-induced biochemical modifications by A. W. Feldman (1971). During 1955–1975, every suggested method of mechanical inoculation, pseudografting, and plant bridging was tried. A great deal of effort was also given to epidemiologic studies and to insect transmission experiments. The latter required testing a wide spectrum of suspected insect vectors.

Even though these research activities were conducted for nearly 20 yr with a high degree of conscientiousness, persistence, and ingenuity by the FAO experts and their Filipino counterparts, the cause of cadang-cadang remained unknown. In 1972 an FAO review mission, consisting of K. G. Heinze and R. A. Robinson, was sent to the Philippines to assess the status of cadang-cadang research and to see if the project could be brought to a close. Instead, the mission concluded that continuation of cadang-cadang research was essential. Although the disease seemed to have become less destructive, the possibility existed for its spread to such major growing areas as Mindanao and to other countries of Southeast Asia. The possibility also existed of cadang-cadang infecting oil palms. The mission concluded that another research approach was necessary, especially for the more sophisticated areas of investigation. FAO then sought assistance from research institutes in developed countries that could offer a firm and continuous linkage to the work under way in the Philippines. This linkage was established with the Department of Plant Pathology, Waite Agricultural Research Institute, University of Adelaide, South Australia. In 1973, J. W. Randles of that institute initiated a new phase of research on cadang-cadang. Also participating were R. I. B. Francki of the same institute; G. Boccardo of the C.N.R. Plant Virus Laboratory, Turin, Italy; B. Zelazny, FAO entomovirologist; and a number of Filipino scientists. Randles' work led to the discovery (16) of two low molecular weight RNAs uniquely associated with diseased tissues. He then hypothesized that the disease was caused by a viroid. This was only 1 yr after the recognition of viroids as the smallest known agents of infectious diseases (7).

The viroidlike structure of the anomalous RNA associated with cadang-cadang disease was described in 1976 (19). In 1977 the successful transmission of the RNAs to coconut species was reported (18), and in 1979 its detection in the African oil palm (*Elaeis guineensis* Jacq.) and in the Buri palm (*Corypha elata* Roxb.) was confirmed (17). Clearly, research on cadang-cadang has moved quite rapidly during the past 6 yr and a succession of important events has taken place. Although the cause of the disease is no longer a mystery, many important facts remain to be discovered. The excellent work of the Filipino scientists assigned to the project and the continued support of the government and of the Waite Institute give assurance that this research will continue to be rewarding.

Lethal yellowing. FAO's involvement in lethal yellowing research in Jamaica started in 1962 with W. Carter and R. K. Latta, who served in the country until 1965. They were followed by N. E. Grylls (1966–1968), K. G. Heinze (1968–1971), and M. Schuiling (1972–1975), all entomologists specializing in insect-virus transmission. They were assisted by a number of other specialists and consultants, including T. J. Grant (plant pathologist/virologist), R. A. Whitehead (botanist/plant breeder), K. Sakimura (thysanopterist), and A. F. Posnette (virologist). N. A. Bor, FAO associate expert, also worked with the project from 1966 to 1968. Close collaboration throughout this period was maintained with the local Ministry of Agriculture and Lands, the University of West Indies, and the Coconut Industry Board. During the last phase, collaboration was extended to the team of the British Overseas Development Ministry (ODM).

In some ways, the pattern of research in Jamaica was similar to that of cadang-cadang in the Philippines. The first phase was directed at studies on symptomatology and epidemiology, on the effect of minor elements, and on transmission tests with dodder, fungi, and nematodes. One full year was devoted to mechanical transmission experiments. Effort was also concentrated on insect transmission. As in the case of cadang-cadang, the cause of lethal yellowing remained unknown. In 1972 three independent reports associated lethal yellowing with mycoplasmalike organisms in sieve tubes of coconut tissues (1,9,13).

Further evidence on the mycoplasma nature of the disease was obtained by demonstrating remission of symptoms in infected palms after treatment with tetracycline (10). Based on these findings, the research effort in Jamaica was reoriented toward a mycoplasma etiology. Many transmission experiments were conducted with leafhopper species (sensu latu), planthoppers (Fulgoroidea), Cicadidae, and a few selected aphids. When FAO research had to be interrupted for operational reasons, responsibilities were absorbed by the ODM team. Meanwhile, FAO catalyzed the establishment of the International Council on Lethal Yellowing (ICLY). This council was formed in 1973 in Florida to promote collaborative research projects on the disease, identify research priorities, attract new expertise to the problem, and organize future meetings. Approximately 40 scientists from nine countries are now members of ICLY, and FAO provides the secretariat to this organization in addition to publishing information on its activities in the FAO yearly progress report on coconut breeding.

Another important role played by FAO in research and control of lethal yellowing has been the collection of coconut germ plasm from various areas of the world and testing it for resistance in Jamaica (24). The outstanding results obtained in these tests were the basis of the recent working hypothesis proposed by FAO on the origin of lethal yellowing and on its coidentity with other lethal diseases of coconut (5).

Destructive diseases of coffee. *Coffee berry disease.* The solution to this problem in Ethiopia had to be found within the realm of the socioeconomic system of growing coffee. Because chemical control was not possible, the only alternative was to search for resistance in the crop. Ethiopia, being the center of diversification of *Coffea arabica,* offered wide genetic diversity that needed to be explored. Preliminary observations had shown that resistance of coffee trees grown on the same farm could vary from complete CBD susceptibility to near immunity. A 7-yr selection crash program was launched, and millions of coffee trees were inspected (20). Of these, only 650 conformed with the desired combined characteristics of resistance, yield, and quality. Seed from these trees were planted and the resulting seedlings checked for homozygosis. During the 18 mo these seedlings were growing in the nursery, artificial inoculation methods and specially developed laboratory tests were used to check the resistance level and yield of the mother trees. Good evidence was obtained on the horizontal nature of the resistance (22). Seedlings that passed all tests were planted where CBD was most severe and allowed to produce their first crop. They were then reexamined for level of horizontal resistance to CBD and other pathogens and for yield/quality characteristics. In 1978 a total of 200,000 seeds of one selected line were distributed to growers. In 1979 this number was increased to 6,000,000 seeds of four lines. All this material combines higher than average resistance to *Gibberella xylarioides.* This is essential to the modernization of coffee growing in Ethiopia, which is now undergoing a rapid change from a traditional to a modern production system (23).

Thus, the FAO assistance given by R. A. Robinson, R. G. White, N. A. Van der Graaff, and R. Pieters, fully integrated with the work of the Institute of Agricultural Research at Jimma, solved in a relatively short time a very serious disease problem and contributed to the modernization of a major sector of Ethiopian agriculture.

Coffee leaf rust. FAO assistance to Latin American countries, including Brazil, Costa Rica, Ecuador, Honduras, Nicaragua, and Peru, facing this problem has evolved along several different lines, including research and actual field control operations. In the research area, major concentration has been on developing coffee lines with horizontal resistance (HR) to *Hemileia vastatrix.* This work was undertaken in collaboration with the Department of Genetics of the Instituto Agronomico in Campinas, Brazil. Most of the available resistance in coffee to this fungus is vertical resistance, which is of dubious value in a perennial crop that is replanted every 25–50 yr. The first objective of the Campinas research project was to develop suitable methodology to measure the various components of HR.

The standardized leaf disk method developed by A. B. Eskes (6) has proved highly reliable, being accurate and capable of measuring different parameters of HR. Of these, latent period and spore production have shown the most significant correlation with field and greenhouse measurements. With the standardized leaf disk method, transgressive segregation has been demonstrated in some coffee crossings grown in Campinas, indicating the polygenic nature of such resistance. With this method, a large number of coffee trees in

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breeder's populations can be screened and productive individuals with high levels of HR selected. The F_2 progeny of the Catuai × Agaro cross show promise.

Cereal diseases and the IPHR. One area in which FAO has taken research leadership during recent years is in breeding for stable resistance. The FAO International Programme on Horizontal Resistance (IPHR) started in 1975 as a result of a recommendation of the ad hoc Governmental Consultation on Pesticides in Agriculture and Public Health held in Rome, Italy, that year.

The main objectives of IPHR are to 1) provide convincing demonstrations of the validity of horizontal, ie, durable resistance, 2) develop methods for accumulating such resistance in crops, and 3) assist national institutes in producing new high-yielding, good quality local cultivars with comprehensive horizontal resistance to all locally important parasites. These objectives have been met in part or in total despite the limits of time and some administrative difficulties.

A typical IPHR research project on cereal diseases has been conducted by M. A. Beek, FAO pathologist/plant breeder, working at the Centro Nacional de Pesquisa do Trigo at Passo Fundo, R.S., Brazil (2). The first step in 1976 was to select 18 wheat cultivars to be parents in the first crossing population. Cultivars were selected on the basis of well-defined criteria, ie, suspected absence of vertical resistance, heterogeneity, synchronism in growth cycle, long cultivation without serious yield losses, and valuable agronomic characteristics.

Each wheat population is named with the letter G_n, in which n is the number of generations a population has been grown. A random polycross is achieved by planting 12-row strips of female parents between six-row strips of male parents in a 0.5-ha plot. The female rows are sprayed with a male gametocide (Ethrel) and pollinated by the untreated male rows. In each population, this results in both open cross-pollination and self-pollination. Artificial inoculations are performed only from G_3 onward, mainly to break down vertical resistance and to enable screening for horizontal resistance. Recurring selection is done only on-site in Passo Fundo, starting with the G_3 population. Multiplication and crossing is done during the off-season in Brasilia.

Genetic advances and accumulation of horizontal resistance are measured at 3-yr intervals by field trials specially designed to assess yield losses. The original parent mixture is compared in these trials with the last screening generation and with two leading commercial cultivars. In 1978, the G_5 generation was evaluated in this manner and was shown to outyield both the original mixture (by 15%) and the best commercial cultivars. Diseases and pests were at a low level in 1978 when the highest average yield for a 30-yr period was obtained. Although no conclusive evidence of the effect on yield of pests and diseases was obtained, indications were good that this effect on the G_5 population was less than that on the original mixture. These early results offer a good demonstration of the feasibility of horizontal resistance breeding.

An estimated 20,000 individual plants were selected in the G_5 population. Only the best 20% of the seed from these plants was multiplied as G_6 in Brasilia. A comparable, if not greater, genetic advance is expected in the G_7 population now growing in the fields at Passo Fundo.

When the first lines resulting from this program are available to growers, they will be only "stopgap" cultivars. Although superior to commercial cultivars, they will soon be replaced by better cultivars derived from further progress of IPHR.

The value of this work to Brazil and other countries facing similar pest and disease situations can be appreciated only if one considers that the bulk of the wheat crop in Brazil is now sprayed at an annual cost of $30 million a year and that a wheat deficit costs the country $500 million annually.

The Pathosystem Concept

It is not possible in this article to give all the details of the work done by FAO in plant disease research and control over the 35 yr of its existence. The examples presented illustrate the magnitude of the problems and complexities inherent in this type of international assistance and give an idea of some of the accomplishments.

The emphasis of FAO's work in plant pathology has shifted greatly over the years. At first, it was thought that with time and the necessary financial inputs, western technology could easily be transferred to less developed countries and, in the plant protection field, chemical control could solve most if not all plant disease problems. This thinking was strengthened by the discovery of powerful systemic fungicides that could control a great array of plant diseases even under the most unfavorable conditions in the tropics. Then with the "green revolution" came the great hope that crop production problems could be solved by conventional plant breeding and by the transfer of a collateral package of modern technological inputs.

It was soon recognized that large-scale crop failures due to plant parasites were still possible as a result of sudden breakdowns of vertical resistance or pesticide effectiveness. Serious reconsideration of the whole question of plant disease control strategies became necessary, particularly in the developing world. The concept of the plant pathosystem, put forward by a former FAO expert, R. A. Robinson (21), was developed at that time. The concept originated in Africa and was written in particular for the developing countries. For the first time, the various plant protection and plant breeding disciplines were brought together in a holistic manner to provide a better understanding of the various pathosystem components.

Through this understanding, practical strategies were suggested to achieve and maintain the type of balance that is the basis for survival in any evolutionary system, including that of man. The pathosystem concept was adopted as the basis of the FAO International Programme on Horizontal Resistance. Its validity under subsistence farming conditions has already been confirmed by the work of Putter (14,15) and Van der Graaff (23).

A few years ago, in considering the risks and advantages of genetic homogeneity in modern crops, D. R. Marshall (11) stated that "the real problem is that although scientists have failed to control all the major parasites of crop plants, they act, in the development and deployment of improved varieties, as if they had." Evidently, he was referring to the fact that selection for resistance was made only in the nurseries of small plant breeders and not in production fields; that selection was made under very special "clean crop" conditions and not under the conditions of the final user; and that selection was made through manipulation of a few single genes that were short-lived but easy to handle. This situation is now changing at both the national and international levels. FAO is proud to have assisted in this change.

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