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Plant Pathology and the

Fig. 1. Early work that led to the establishment of the International Soybean Program (INTSOY) included the discovery that soybeans were a productive crop in tropical and subtropical locations. Much of this work was done in India, where this photograph was taken.

In the continuing search for ways to improve world agriculture and feed the world's hungry people, it is unrealistic to expect any one simple solution. The complexity of mankind's social, religious, and economic patterns and the ecological diversity of the globe on which we live require different strategies for different situations.

Playing a role in this complex but vitally important endeavor is a 7-year-old organization called the International Soybean Program (INTSOY). Based in the colleges of agriculture of the University of Illinois at Urbana-Champaign (UIUC) and the University of Puerto Rico—Mayaguez Campus (UPR-MC), INTSOY is a research and outreach program dedicated to fulfilling the potential of soybeans (*Glycine max*) to help developing nations raise incomes and nutritional standards among the rural and urban poor.

INTSOY is multidisciplinary and interdisciplinary, with research workers in plant breeding, agronomy, soils, microbiology, plant pathology, weed science, entomology, food science,

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International Soybean Program (INTSOY)

nutrition, agricultural engineering, production economics, marketing, and sociology. INTSOY is global in orientation; the INTSOY soybean variety trials have been conducted by cooperators in over 100 countries. INTSOY has cosponsored with national organizations six conferences, including three regional conferences on all aspects of soybean production, protection, and utilization (one conference each for tropical America, Africa and the Middle East, and Asia and Oceania) and three topical conferences (on soybean rust, irrigated soybean production, and seed quality).

In addition to outreach and basic and applied research, INTSOY includes a soybean breeding program designed to produce tropically adapted soybean lines with high yields, yield stability, and disease and pest resistance. Distributed throughout the world to national and other international programs via the INTSOY variety trials program, these advanced lines are used by INTSOY cooperators for further selection and possible release.

INTSOY's various activities are funded largely through grants and contracts from U.S. federal and international sources. Major funding for research is from contracts with the U.S. Agency for International Development (USAID). Grants have come from USAID and the Rockefeller Foundation. INTSOY has two major country programs: In Sri Lanka, a countrywide soybean development program is supported by United Nations agencies (FAO and UNDP), with utilization work supported by UNICEF and CARE; in Peru, work in soybean production, economics, food science, and extension is supported by USAID.

Beginnings of INTSOY

The origins of INTSOY are rooted in the successful efforts of University of Illinois faculty and their colleagues working at agricultural universities in the states of Uttar and Madhya Pradesh, India, to grow soybeans in India during the late 1960s (Fig. 1). The original impulse, which has since broadened, was to exploit the superiority of soybeans as a source of high-quality protein and oil for direct use as human food.

INTSOY was created in 1973 as a university-based, internationally oriented organization; it does not have a corporate identity separate from its university sponsors. INTSOY staff members are an integral part of academic departments at the University of Illinois and the University of Puerto Rico. This approach brings to the academic departments an international orientation in teaching, research, and outreach and serves to strengthen the departments as well as INTSOY. INTSOY is thus a university-

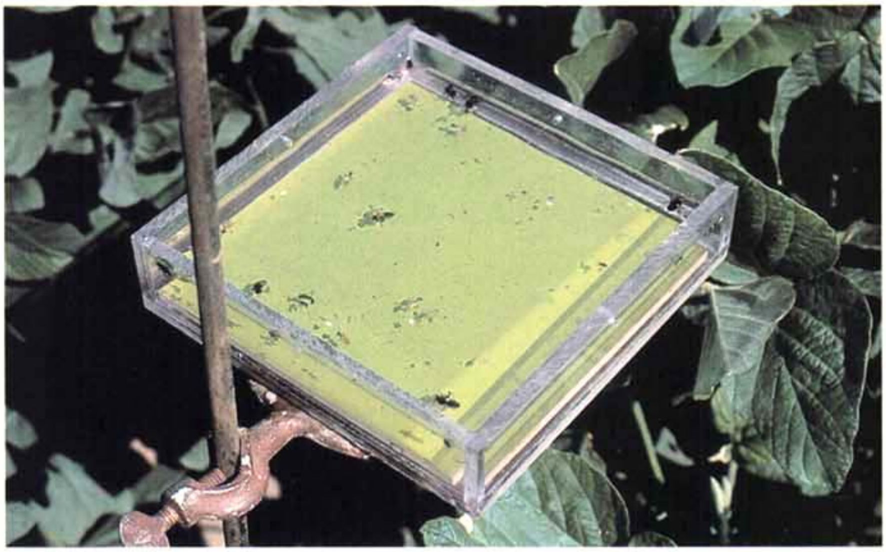


Fig. 2. The horizontal ermine lime (HEL) trap developed by INTSOY to monitor aphids and other insects visiting soybean fields.

Fig. 3. Whitefly-transmitted viruses take a severe toll in tropical legumes, especially in parts of Asia. Evidence suggests that the virus shown here causing symptoms in soybeans in Sri Lanka may be the same as that causing yellow mosaic diseases of mung beans and soybeans in India and Thailand.

Table 1. Reactions of soybean cultivars to seven soybean mosaic virus (SMV) strains obtained from the USDA soybean germ plasm collections[a]

Soybean cultivars	Symptoms caused by SMV strains[b]						
	SMV-G7	SMV-G6	SMV-G5	SMV-G4	SMV-G3	SMV-G2	SMV-G1
Clark	−/M	−/M	−/M	−/M	−/M	−/M	−/M
Rampage	−/M	−/M	−/M	−/M	−/M	−/M	−/M
Davis	−/M	−/M	−/M	−,N/M,N	−/−	−/−	−/−
York	−/M	−/M	−/M	−,N/M,N	−/−	−/−	−/−
Marshall	N/N	N/N	−/−	N/N	N/N	N/N	−/−
Ogden	N/N	−/−	−/−	N/N	N/N	−/−	−/−
Kwanggyo	N/N	N/N	N/N	−/−	−/−	−/−	−/−
Buffalo	N/N	−/−	−/−	−/−	−/−	−/−	−/−

[a] A list of accessions from which SMV isolates were obtained is available on request from the authors. From Cho, E.-K., and Goodman, R. M. 1979. Phytopathology 69:467-470.

[b] Reactions on inoculated primary leaves/reactions on noninoculated trifoliolate leaves: − = symptomless, no virus detected by Top Crop indexing; M = mosaic symptoms; N = necrosis.

based variant of the international center concept. While not officially recognized as an international center by the Consultative Group for International Agricultural Research (CGIAR), INTSOY has assumed a global mandate for tropical soybean research and cooperates with several of the CGIAR centers.

Title XII of the International Development and Food Assistance Act of 1975 provides for expansion of internationally oriented agricultural research and extension programs by U.S. universities. The idea is to identify commodities or in some cases multidisciplinary activities (such as integrated crop protection) that need development and to fund programs for cooperative investigations in these areas between universities in the United States and universities or other agricultural institutions in the developing world. By this means, it is reasoned, the resources of U.S. agricultural universities will be focused on problems of the developing agricultural economies in the Third World. At the same time, U.S. universities will be strengthened by long-term involvement in this challenging and crucial aspect of world development. INTSOY is an example of how such a program works.

The role of plant pathologists in the INTSOY program is to provide the research findings on which sound disease control or management recommendations and the development of disease-resistant tropical soybean lines can be based. The INTSOY plant pathology research program covers a wide spectrum of activities, from breeding for disease resistance to fundamental studies on pathogen genetics, from studies on control of seedborne pathogens to field epidemiology.

Virus Diseases

Studies on virus diseases by INTSOY plant pathologists have concentrated on aspects particularly pertinent to soybeans grown under tropical and subtropical conditions. Soybean mosaic virus (SMV) has received considerable attention because this potentially serious virus is already widely distributed owing to a high incidence of seedborne virus in soybean germ plasm collections and to the generally more serious nature of virus diseases in tropical than in temperate zones. Research has also focused on the group of tropical diseases caused by whitefly-transmitted viruslike pathogens, one of which caused serious yield losses in soybeans in India in the late 1960s. In addition to research contributions, staff members and students associated with INTSOY's virology program are engaged in several outreach activities.

Seed transmission of soybean mosaic virus. SMV is a member of the large and agriculturally important potato virus Y group and is transmitted in a nonpersistent manner by numerous species of aphids and through soybean seeds. SMV has a relatively narrow host range and is not known to persist from season to season in noncultivated vegetation or other crops. Seed transmission thus is important in the geographical and seasonal spread of the virus.

Earlier workers had reported variation in the incidence of seed transmission in different soybean cultivars and suggested that SMV infection reduced the germination ability of seeds from infected plants. We were interested to know whether some lines or cultivars transmitted SMV through seeds. The entire tropical germ plasm collection and some 500 temperate accessions were screened in a multistage effort to identify accessions with low or nil transmission of SMV through seeds (6). Seed transmission occurred in all the accessions tested, but five had transmission rates consistently below 0.25%, compared with rates of 2–20% found in most accessions (7). More recent results show, however, that seed transmission of SMV in temperate soybean lines also depends on the genetic attributes of the particular SMV isolate or strain. Thus, we do not yet know how stable this resistance will be in the field where more than one virus strain may occur.

Research on genetic resistance to seed transmission of SMV in soybeans has also led to other useful information. Results of studies on the mechanism of seed transmission suggest that infection of the embryo via the maternal parent is necessary and sufficient to account for the incidence of virus transmission through mature seeds. However, SMV appears not to have a direct effect on seed viability; rather, the presence of SMV appears to result in an increased incidence of the seedborne fungus, *Phomopsis sojae* (8).

Resistance and plant breeding work. Little attention has been paid in the past to assessing the virulence of SMV isolates used in developing SMV-resistant soybean cultivars. As the basis for developing tropically adapted soybeans with SMV resistance, INTSOY researchers conducted a study using 100 SMV isolates collected from soybean germ plasm accessions representing diverse geographical origins. Isolates were grouped according to whether they did or did not infect selected soybean cultivars previously reported to possess SMV resistance and, if infection occurred, the type of symptom produced. The results (Table 1) are interesting because breeding programs for SMV resistance in the past have used isolates belonging to the least virulent strains (G1 and G2). Moreover, the results suggest that different genetic systems, possibly different genes, for SMV resistance exist in the various SMV-resistant cultivars.

A considerable effort has been made over the past few years to identify sources of resistance to SMV infection in tropically adapted soybeans. Initially, tropical germ plasm was screened using a single isolate of the virus. Germ plasm accessions resistant to SMV in the initial screening have since been repeatedly tested with representative isolates of all seven strains (Table 1); a major genetic study resulted in discovery of one and possibly two new dominant genes for resistance to SMV (1). Populations derived from crosses of SMV-resistant and high-yielding but susceptible tropical cultivars are now being advanced and evaluated. Lines resulting from this breeding program will in the next few years be tested in INTSOY variety trials at several tropical locations where SMV is important in soybean production. The sources of SMV resistance identified by INTSOY, as well as the SMV strain classification scheme, are also used in several temperate zone soybean breeding programs.

Aphid transmission and epidemiology. Cooperative work by INTSOY virologists and entomologists has centered on aspects of aphid transmission of SMV and on developing methods for monitoring aphid vectors in the field.

SMV is transmitted in a nonpersistent manner from plant to plant in the field by insects in the family Aphididae. Some 24 species of aphids are reported as vectors of SMV, and INTSOY researchers have added seven more to the list. In most of the world, aphids do not colonize soybeans, and the virus is transmitted by transient alatae (winged forms). The epidemiology of nonpersistent transmission in the field by transient aphids has received less research attention than colonization of the crop by vector species. INTSOY researchers have therefore devoted considerable effort to work on which to base sound recommendations for controlling or avoiding SMV infection in tropical soybeans (11).

Central to this work was the development and validation of a new type of insect trap having the same degree of attractiveness or repellancy to aphids as the canopy of the crop (10). The horizontal ermine lime (HEL) trap (Fig. 2) consists of a rugose-textured ceramic tile; the color of the tile closely resembles that of soybean leaves based on reflectance spectrometry. The tile is submerged in a 50% aqueous solution of ethylene glycol held in a plastic tray; use of liquid in the trap (earlier designs used tiles coated with a sticky substance) reduces the frequency of sample collections and preserves specimens without altering the species composition. The height of the trap can be adjusted to approximate the level of the canopy throughout the season. HEL traps have been used in a variety of field epidemiology experiments in which such factors as inoculum density, distance, barriers, planting date, and canopy color have been investigated for effect on the rate of spread of SMV (11). Several INTSOY cooperators in various countries are now using the traps in experiments.

Another INTSOY contribution to work with SMV vectors is the use of live-trapping to assess the relative efficiencies of SMV transmission by various aphid species. Vertical nylon nets are erected downwind from a field of SMV-infected soybeans. Aphids landing on the windward side of the net are individually placed on healthy caged soybean seedlings. Each aphid is later retrieved, coded, and preserved in ethanol for identification. The seedlings, marked with the same code, are kept in an insect-free greenhouse. Transmission of SMV is determined by infectivity or serological indexing. Results from a location in Illinois (Table 2) show that of more than 60 aphid species visiting soybeans, 5 contributed over 93% of the transmission. A highly abundant but relatively inefficient transmitter (*Rhopalosiphum maidis*) was as important in virus transmission as were relatively less abundant but more efficient species (*Myzus persicae* and *Aphis craccivora*).

Whitefly-transmitted viruses. For years, tropical agriculturalists have been concerned with a group of damaging diseases caused by viruslike pathogens transmitted by the tropical whitefly (*Bemisia tabaci*). The etiology of these diseases remained obscure, however, until work on the causal agent of bean golden mosaic (mosaico dorado) disease showed that the pathogen was also sap-transmissible. Soon thereafter, independent work by plant pathologists at the Centro Internacional de Agricultura Tropical (CIAT) in Colombia and at INTSOY showed that bean golden mosaic was caused by an unusual virus now recognized as a member of the newly described geminivirus group (4,5). Certain geminiviruses, including maize streak and Chloris striate mosaic viruses, are transmitted by leafhoppers; others, such as bean golden mosaic, Euphorbia mosaic, and tobacco leaf curl viruses, are transmitted by *B. tabaci* (Fig. 3). Geminiviruses are unusually small and occur as paired isometric particles. Within each particle is a circular, single-stranded DNA (ssDNA) molecule with molecular weight of $7–8 \times 10^5$. Recent results from research supported in part by INTSOY suggest that the geminivirus genome consists of two of these small DNA molecules, each having the same size and circular topology but differing in nucleotide sequence and thus genetic content. Geminiviruses are the only plant viruses with ssDNA and also are unlike any other virus known in animals or bacteria. Because of their unusually small size and evidence that they replicate in the nucleus of plant cells, geminiviruses are of interest in fundamental studies on the mechanisms by which genes function in plant cells; they may be useful in the future as tools for genetic engineering in plants.

A major disease of tropical legumes, including soybeans, in South Asia has been shown to be caused by a geminivirus. This work, done by a former INTSOY research assistant and his colleagues, points up an immediately practical area of geminivirus research that will receive increasing attention in the future. Little is known about relationships among the geminiviruses. In an attempt to foster research in this area, INTSOY is cooperating in a worldwide study to serologically compare the legume geminiviruses.

Yield loss studies. Losses caused by virus infection are not well documented. This problem is particularly acute in the tropics, where a combination of soil and weather conditions, complicated cropping sequences, lack of knowledge among growers, and often severe economic constraints are responsible for wide differences among yields obtained on experimental stations and on farms. INTSOY has attempted to stimulate interest in the analysis of yield losses caused by virus diseases in soybeans while, through its own research program, adding to the knowledge base that can be

Table 2. Abundance, SMV transmission efficiency, and relative SMV transmission efficiency of live-trapped aphids, Urbana, IL, 1976–1978[a]

Species	Specimens trapped (no.)	Relative abundance (%)	SMV transmission per species (%)	SMV transmission contributed by species (%)
Aphis craccivora	109	6.4	13.8	20.8
Macrosiphum euphorbiae	145	8.5	8.3	16.7
Myzus persicae	148	8.7	12.2	25.0
Rhopalosiphum maidis	605	35.4	3.1	26.4
Rhopalosiphum padi	81	4.7	3.7	4.2
Subtotal (5 species)	1,088	63.7	6.2	93.1
Other species (> 55 species)	621	36.3	0.8	6.9
Total	1,709	100.0	4.2	100.0

[a] From Halbert, S. E., Irwin, M. E., and Goodman, R. M. 1981. Ann. Appl. Biol. In press.

Fig. 4. INTSOY virologists are working to produce tropical germ plasm accessions free of known viruses for use in West Africa and South America. This germ plasm collection in Puerto Rico was rogued and serologically indexed to assure that seeds were harvested from virus-free plants.

Fig. 5. Machismo disease of soybeans is a serious threat to soybean production in South America. Transmitted by leafhoppers, the causal agent is probably a mycoplasmalike organism.

used to make decisions about how and when to intervene with disease or vector control tactics (14).

Current work at UIUC is designed to provide information on the parameters of yield affected by SMV infection of soybeans and to relate the incidence of such infection to virus spread via aphids in the same season and via seed transmission into the next generation. In most of the world, growers produce their own seeds for planting the following season. It is important that the quality of the seeds saved be safeguarded to prevent a virus epidemic resulting from inoculum originating in the grower's own seed stocks. Additionally, INTSOY research provides a set of validated experimental designs and methods that can be adopted by cooperators for region- or location-specific research, which is often needed to arrive at workable practices for a given agricultural situation.

Outreach activities. The INTSOY soybean virology group, with cooperating staff in agricultural entomology, plant breeding, and seed pathology, maintain an active interest in conveying knowledge and scientific resources to cooperators in many countries. For example, in a cooperative project with the International Institute of Tropical Agriculture (IITA) in Nigeria, INTSOY virologists have recently produced a collection of tropical soybean germ plasm free of known viruses for introduction, through official quarantine channels, to West Africa (Fig. 4). A similar collection is being provided to the Instituto Colombiano Agropecuario (ICA) for screening for resistance against a serious disease called "machismo" or "amachamiento" (Fig. 5). At IITA, the germ plasm collection is needed for research to diversify the soybean genetic base in use for production in the lowland humid tropics. Improved seed quality and a favorable response to indigenous *Rhizobium* strains are two of the principal concerns of the work at IITA.

INTSOY virologists have also contributed, by consultation and a variety of other aids, to the soybean programs of Colombia, Ghana, Guatemala, India, Mexico, Nigeria, Peru, Sri Lanka, and Thailand (Fig. 6). Ongoing collaborative research includes work on whitefly-borne geminiviruses with colleagues in Costa Rica, India, the Philippines, and Thailand and on other virus and mycoplasma diseases with scientists in Colombia, Mexico, and Peru.

As a university-based program, INTSOY is particularly well situated to serve as a center for graduate education. In addition to the excellence of study at a major land-grant university, INTSOY research assistants gain from the experience of being an integral part of the research staff and contribute significantly to progress in INTSOY's program of internationally oriented soybean research. Since research in virology was begun under INTSOY auspices in 1974, graduate students from Thailand, Korea, the Philippines, Canada, and the United States have participated.

Fungal and Bacterial Diseases

Producing high-quality soybean seeds involves proper harvesting, storage, planting, and other practices. Soybean seeds are vulnerable to a wide variety of microorganisms that decay seeds, delay germination, or lower seedling vigor. Seeds carry microorganisms from one season to another and from one location to another. Seed quality is important not only in seeds for planting but also in seeds for commercial uses. As in the case of seedborne viruses, seedborne fungi and bacteria are easily distributed with infected seeds, making disease control more difficult.

The lack of high-quality seeds for planting is often a limiting factor in the production of soybeans and other edible legumes in the tropics and subtropics and adversely affects the quality of food and other products derived from these crops. INTSOY pathologists, agronomists, and agricultural engineers and their graduate students at UPR-MC and UIUC have cooperated in a variety of research programs concerned with the pathological factors affecting soybean seed quality in the field and in storage and with means of controlling them. Some of the research has been done by graduate students doing dissertation research at institutions in Brazil, Colombia, India, Nigeria, and Taiwan.

Seedborne pathogens and seed quality. A major emphasis has been placed on studying the seedborne nature of various fungi and of *Bacillus subtilis*. Host-pathogen relationships, epidemiology, host ranges, and the effect of disease organisms on oil and flour derived from infected seeds have been investigated.

Seedborne fungi of soybean have a greater influence on seed quality than previously understood. In areas where moisture conditions are high at or close to harvest, soybean seed quality can be greatly reduced. Many of the methods for evaluating seed quality do not take into consideration the effect of seedborne fungi. Seed pathogens colonize the cell layers of the soybean seed coat (Fig. 7) and attack the embryo during germination. The number of viable seeds in a contaminated seed lot is actually higher than most germination tests would indicate; when seedborne fungi are controlled, better quality seeds are obtained for the next year's crop, for processing, and for use as food and feed.

INTSOY pathologists have defined the role that various microorganisms play in reducing soybean seed quality and the environmental factors affecting their expression. Among the most important fungal pathogens are *Phomopsis* spp. (*Diaporthe phaseolorum* var. *sojae*), which cause pod and stem blight and seed decay; *Colletotrichum dematium* var. *truncata*, which causes anthracnose and seed discoloration; *Cercospora kikuchii*, which causes leaf spotting and purple seed stain; and *Cercospora sojina*, which causes frogeye leaf spot and pod spot.

Because these organisms can infect and colonize seeds without causing overt symptoms, methods for detecting seedborne fungi are important aids in assessing potential for losses and need for control measures. Paraquat, a harvest-aid herbicide, was used at UIUC to detect latent colonization of leaves, stems, and pods by these fungi (2). Spraying in the field or dipping soybean plant parts in solutions of paraquat promoted symptom development and sporulation of fungal pathogens at least 2 weeks before those on untreated plants or plant parts. Breeders can use this technique to test for disease susceptibility before soybean plants mature, and pathologists can use the technique to measure the level of fungal infection in the field, determine whether a fungicide should be used to protect seeds from infection, and study the epidemiology of the fungi involved. The technique is simple and can be used in laboratories in developing countries.

Phompsis spp. and *C. dematium* var. *truncata* (or closely related species) also affect the quality of other large-seeded legumes. In a cooperative study with CIAT, seeds of *Phaseolus* were found to be affected by these fungi in the same manner as soybean seeds were. At UPR-MC, similar results were obtained with chickpea, pigeon pea, and cowpea seeds.

Infection by *Phomopsis* spp. in soybeans grown in Illinois increased the number of symptomatic seeds in a seed lot, reduced the test weight, and increased the number of split seeds. Oil and flour quality were reduced when high percentages of infected seeds were present. A high correlation was found between disease incidence and rainfall during pod fill, suggesting that moisture rather than temperature or geographic area was the dominant factor in disease development. A similar situation was found when the effect of planting date on soybeans containing seedborne *C. dematium* var. *truncata* was studied in a cooperative program at J. Nehru Agricultural University, Jabalpur, India. Seeds

Fig. 6. INTSOY staff members discussing the harvest with an extension agent and a farmer in Sri Lanka. An important part of INTSOY's worldwide involvement with soybeans is the opportunity to visit research workers, extension personnel, and growers in various parts of the world.

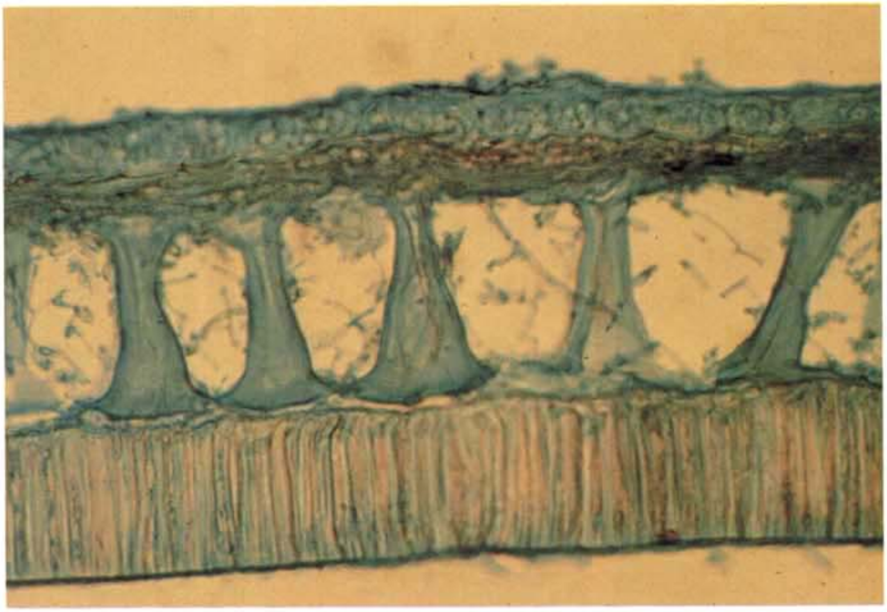
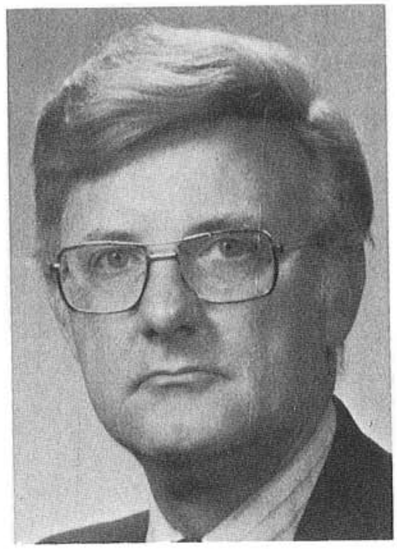


Fig. 7. Mycelium of *Phomopsis* sp. colonizes the "hourglass" cell layer of the soybean seed coat and penetrates into the upper palisade cell layer and lower parenchyma cell layer.

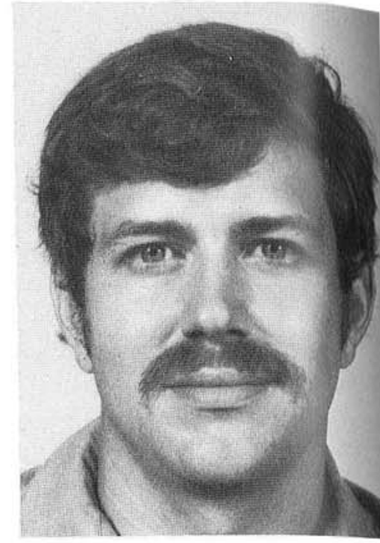
Robert M. Goodman

Dr. Goodman, a native of upstate New York, is an associate professor in the Department of Plant Pathology and a member of the INTSOY staff at the University of Illinois at Urbana-Champaign. He studied at John Hopkins University and Cornell University and received his Ph.D. from Cornell in 1973. He held a NATO postdoctoral fellowship at the John Innes Institute, Norwich, England, before being appointed to the Illinois faculty in 1974.



James B. Sinclair

Dr. Sinclair, professor of plant pathology at the University of Illinois at Urbana-Champaign (UIUC), received his Ph.D. from the University of Wisconsin–Madison in 1955. He held a postdoctoral position with J. C. Walker until 1956, when he joined the Department of Botany and Plant Pathology at Louisiana State University. In 1968, he moved to UIUC to develop the international program in plant pathology and thus become a charter member of INTSOY.



Paul R. Hepperly

Dr. Hepperly is an assistant professor in the Department of Crop Protection at the University of Puerto Rico—Mayaguez Campus and director of the Puerto Rico component of INTSOY. A native of Illinois, Dr. Hepperly studied at the University of Illinois and earned his Ph.D. in plant pathology there in 1979.

harvested after the monsoon period were of higher quality and had a lower incidence of seedborne fungi than seeds harvested during the monsoon. This suggests that soybean seed fields should be grown in areas where dry conditions prevail during the maturation period of the seeds.

Weeds associated with soybean fields at UIUC were found to be infected with species of *Colletotrichum* and *Phomopsis* capable of infecting soybeans (9). With the Universidade Federal de Viçosa, Brazil, cooperating, a similar situation was found on weeds in soybean fields there. Moreover, experience shows that in the presence of weeds in soybean fields, soybean seed quality is substantially reduced.

Another seedborne fungus studied at UIUC was *Macrophomina phaseolina*, the cause of charcoal rot. This disease can cause severe yield losses in soybeans when warm, dry conditions persist. Losses caused by charcoal rot have been recorded in Colombia, Ecuador, India, and other countries where soybeans are planted at the end of the rainy season and allowed to mature in the dry season. The disease is also economically important in scattered areas of the United States when conditions favor its development. Symptoms of charcoal rot, pot and stem blight, anthracnose, and other fungi usually appear when soybean plants are under environmental stress or infected by SMV. Often these diseases are most evident near the end of the growing season when soybean plants begin to senesce.

Bacterial infection of seeds also affects soybean seed quality, particularly when seeds must be stored for any length of time. The factors affecting the storage life of soybeans include initial seed moisture, seed quality, type of storage container, and duration of storage, according to results of an INTSOY study conducted in Puerto Rico. Under ambient conditions, seed viability was lost after 6 months if the seeds were not kept dry by sealing in moisture-impermeable containers. Seeds of poor quality at harvest stored less well than high-quality seeds. Fungicide treatment of the seed did not reduce storage decline, and the incidence of seedborne fungi decreased during seed storage. Viability losses during storage were correlated with increased colonization by *B. subtilis*. In other studies, antibiotic treatment controlled *B. subtilis* and decreased viability losses during storage of seeds at high temperature.

In studies at UIUC, *B. subtilis* was found in soybean seed lots from around the world. This ubiquitous bacterium of soybean seeds is often considered a contaminant in microbiological work. Through indirect evidence and data obtained from the UIUC project, *B. subtilis* was determined to be a pathological factor involved in decay of soybean seed under conditions of high moisture and high temperature. Several tropical countries, including Egypt, Nigeria, Ivory Coast, the Philippines, and Indonesia, report that it is difficult to obtain a stand of soybean planted in soil at 35 ± 3 C. At IITA, for example, not a single seed emerged from a large variety trial planted in moist soil over 35 C; *B. subtilis* was involved.

Control of seedborne pathogens. Two major approaches have been taken to control seedborne microorganisms of soybean: nonchemical and chemical. Good-quality soybean seeds harvested at maturity, dried to approximately 13% moisture, and stored in a cool environment provide excellent seeds for planting or processing. When these conditions cannot be met, seed treatment with a fungicide and/or antibiotic or the use of foliage sprays can reduce the adverse effects of seedborne fungi on seed quality. Many of the more common fungicides are available in developing countries but may be difficult to obtain by individual growers, who may not be educated in their proper use. The most practical solution to improving soybean seed quality for small farmers in the developing countries would be the use of disease-resistant varieties.

Studies on the control of seedborne fungi at UIUC and UPR-MC have included screening the tropical germ plasm collection for resistance to seedborne fungi. As a result, tropical soybean lines have been identified with superior seed quality attributes (12). Also being investigated are use of systemic fungicide sprays to reduce field infection by seedborne fungi (now commonly practiced in seed production fields in the United States), evaluation of various traditional seed dressings, and infusion of fungicides into seeds with acetone, dichloromethane, ethanol, polyethylene glycol, and other solvents (13). Infusion combined with traditional seed dressing gives the best seed protection and offers promise for use on breeders' seeds as well as on those in germ plasm collections.

The first steps toward biological control of seedborne fungi are being taken by INTSOY researchers. Studies on purple seed stain showed that natural infection by *C. kikuchii* reduced the occurrence of *Fusarium* and *Phomopsis* spp. in Puerto Rico but not in Illinois. Seedborne fungi such as *C. kikuchii* that do not appreciably reduce germination may be possible biological control agents for other more damaging pathogens. *Chaetomium* spp. and *Gliocladium roseum*, which are seedborne in soybeans, were inhibitory to a wide range of seedborne pathogens. An antibiotic antagonistic toward *Chaetomium* has been isolated and partially purified.

Infusion of seeds with antibiotics, such as streptomycin sulfate and potassium penicillin G, gives excellent control of *B. subtilis* on soybean seeds. These antibiotics are expensive, however, and use is restricted because they are also used to control human pathogens. Another means of control developed at IITA is mulching soybean fields after planting to allow the soil to cool naturally. Low temperatures or storage in airtight containers helps control both the bacterium and other microorganisms in storage.

INTSOY's international role in seed pathology. The focus on seed pathology has had significant international influence on establishing and developing seed pathology. An important event was the First Latin American Seed Pathology Workshop held in Londrina, Brazil, in 1977. J. B. Sinclair, INTSOY pathologist, was a consultant in the initial planning of the workshop, a participant in the meeting, and an editor for the proceedings (15). The proceedings contain information not previously published in such comprehensive form, including techniques for detecting seedborne fungi and bacteria. Other spin-offs from the INTSOY seed pathology program have been formation of the Inter-American Working Group of Seed Pathologists and establishment of seed pathology committees by the International Society of Plant Pathology and the American Phytopathological Society.

Other Diseases

Soybean rust is one of the major constraints to soybean production in the tropics and some of the subtropics of the Eastern Hemisphere. The disease, caused by *Phakopsora pachyrhizi*, occurs in the wet tropics and subtropics of Central and South America and Africa, and when conditions are favorable, infected plants are severely defoliated (Fig. 8). Realizing the importance of rust and recognizing the values to be gained by cooperative efforts, INTSOY convened and published the proceedings of the Asia-Oceania Soybean Rust Workshop held in Manila in 1977 (3). The delegates defined the problem and developed research needs. The workshop was cosponsored by the Asian Vegetable Research and Development Center (AVRDC) and the Philippine Council for Agriculture and

Resources Research (PCARR). INTSOY and AVRDC are cooperating with the U.S. Department of Agriculture in a study on soybean rust at AVRDC.

Another disease of potential economic importance is the "dead patch" that occurs in soybean-growing areas of southern Brazil. The disease is a root rot complex involving *Rhizoctonia solani* and *Fusarium* spp. Large areas of soybean affected by the disease complex wilt and die (Fig. 9). INTSOY pathologists are working with Brazilian pathologists to understand the etiology of the disease.

Fig. 8. *Phakopsora pachyrhizi* (rust of soybean) causes severe defoliation of soybeans in the Eastern Hemisphere. (Inset) Rust uredia on the lower leaf surface of an infected soybean.

Prospects for Success

The success of the INTSOY program will ultimately be measured by its impact on improvements in the diets and economic well-being of poor people around the world. Many people, including some in high places, still regard soybeans as an industrial crop of little or no use in the struggle for rural development. Many other knowledgeable people, including INTSOY staff and hundreds of cooperators around the world, disagree with this harsh assessment. Few crops are as adaptable to widely differing agricultural niches as soybeans have proved to be. No crop has more diverse uses. Soybeans are readily prepared as a palatable food for people of widely divergent taste preferences and can also be processed by sophisticated methods to make a variety of snacks and foods that mimic other high-protein foods. Soybeans are palatable to animals and can be used to feed livestock. Both protein and oil are present in high amounts in soybeans, and each is among the best of the vegetable sources for these constituents. It thus seems shortsighted not to include soybeans among the crops to play an increasingly important role in tropical as well as temperate agriculture.

Soybeans are not without disease problems. INTSOY plant pathologists at UIUC and UPR-MC believe, however, that soybeans are no more disease-prone then other legumes grown in the tropics and that in some situations soybeans have a clear advantage. Through a continuing program of collaborative research and outreach programs, including newsletters, conferences and published proceedings, site visits, and short courses in the United States and abroad, INTSOY expects to persevere in assisting national and international agricultural research agencies develop programs leading to a greater worldwide role for soybeans in the future.

Fig. 9. *Rhizoctonia solani* and *Fusarium* spp. cause severe stand losses to soybeans in Brazil. Note large patches of dead plants.

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