of practical knowledge of a wide range of sophistication, by what must be admitted to be the scientific method, and neither their accomplishments and skills nor those of societies "en voie de développement" should be ignored or discounted.

We are confident that modern food science and technology has much to contribute to helping the food-deficit nations eat adequately. First, we must find a way of using the best of Western technology without losing sight of the reality of the situation in the third world and without failing to take into account, better than we have done so far, the secondary and tertiary implications of the changes suggested. Second, we must encourage the examination of local problems in terms of the use and improvement of local technologies which are often quite sophisticated and the result of centuries of development. And third, we must inject a greater component of cultural awareness in the education of students to make them more creative in their application of scientific knowledge to local problems and more adaptable to the conditions that exist in developing countries. We should not lose sight of the fact that because of the precarious nature of their food supply, very often developing countries have much more rigid rules governing the production, preparation, and consumption of food than usually is the case in food-surplus societies, and disturbing these rules is a very serious matter. The time is past when "West is best" can be taken for granted; "adapt and adopt" is surely less offensively arrogant and much more to the point.

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Crop Protection to Increase Food Supplies

W. B. Ennis, Jr., W. M. Dowler, W. Klassen

The need for enough food to insure against hunger or the fear of famine was probably one of the strongest motivating forces in history, and the threat of starvation remains a primary concern in many nations. In countries where adequate food is available, consumers are greatly troubled about costs.

Today, pests cause an estimated 30 percent annual loss in the potential worldwide production of crops, livestock, and forests. No part of our food, feed, or fiber supply is immune from pest attack, whether it involves marine life, wild or domestic animals, field crops, horticultural crops, or wild plants. Obviously if losses could be prevented or reduced food supplies would be increased. Although the problems are complex, the best strategy for achieving short-term gains is to make better use of existing technologies in production systems throughout the world.

Nature and Extent of Losses Caused by Pests

Pests of many kinds attack plants during all stages of their growth and attack food or food products after harvest—in storage, during transportation to market, in warehouses, in elevators, in ships, in the supermarket, and in the home after purchase. More than 160 bacteria, 250 viruses, and 8000 fungi are known to cause plant diseases in one situation or another (*1*). Approximately 10,000 species of insects in the United States are destructive enough to be called enemies. About four-fifths of them are injurious to crops (*2*). Likewise, some 2000 species of weeds in the United States and Canada cause economic losses in some crops or situations (*3*). In addition, a wide range of nematode species, birds, rodents, and other organisms continually attack our crops and food supply.

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Pest insects, birds and rodents devour growing crops and lower their yield; they also cause deterioration in product quality. Insects and rodents attack grains and other food products in storage and during transport. Disease organisms kill plants, cause rotting and blemishing of food products, and reduce crop yields and quality. Weeds reduce yield and quality by competing with crops for water, nutrients, light, and space, and also reduce the productivity and efficiency of land use. They poison livestock, interfere with harvesting, and prevent the flow of water for irrigation and drainage. Insects harbor and transmit diseases to plants, animals, and man. Nematodes transmit pathogenic viruses and intensify fungal diseases.

The worldwide annual loss of 30 percent of potential productivity occurs despite the use of advanced farming technology and mechanized agriculture (*2, 4*). In many of the developing countries, losses greatly exceed this figure.

The economic damage caused by pests was highlighted in a special study of the world food problem in 1967 (*5*). Preharvest losses of food and industrial crops due to insects and diseases in 11 developing countries in the Near East were estimated at 23 percent. In Chile, the average losses in yield of potatoes due to late blight have exceeded 20 percent per year. In India, in 1963 and 1964, insects and rodents that attacked grain in the field and in storage caused losses of approximately 13 million tons; such an amount of wheat would supply 77 million families with one loaf of bread per day for a year. In Africa and Asia, the quelea, a grain-eating bird, causes serious losses of rice, millet, sorghum, and wheat crops; indeed, in the Sudan area alone, daily consumption by these birds has been estimated as 3000 tons of grain.

There are other more recent examples. In the United States, birds, primarily blackbirds, destroyed an estimated 6.8 million bushels of corn in 19 major corn-producing states in 1971 (*6*) (1 bushel of corn = 25.4 kilograms). This corn would have been enough to produce over 300,000 hogs. The pork from these hogs would have been equal to the amount normally eaten by 810,000 people in a year. In North Dakota, wild oat reduced wheat production by approximately 19 percent in 1973 (*7*). The total losses due to this weed and the cost of controlling it in the United States and Canada were estimated to be $1.5 billion at 1973 prices. In 1970, southern corn leaf blight reduced U.S. corn production by 15 percent (*8*). This loss of about 800 million bushels of corn contributed to a 20 percent increase in corn prices. The loss to farmers and increased cost to consumers totaled more than $2 billion (*9*).

Indeed, pests can destroy an entire industry. When the boll weevil invaded the southeastern United States, production of Sea Island cotton was no longer feasible. Similarly, cotton production around Tampico, Mexico, has been stopped because the tobacco budworm developed resistance to all available insecticides. Insecticide-resistant tobacco budworms are now threatening cotton production in Texas, Louisiana, Mississippi, and Arkansas.

In addition to the direct losses caused by pests, there are indirect losses. For example, the energy input for crop production is substantial, and yield losses from pests represent a sizable amount of wasted energy.

Pests thus cause losses amounting to billions of dollars annually and are a major factor in limiting crop yields throughout the world. Unless crops and food products can be protected, food supplies will dwindle and become even more critical than they are today. The tragedy is that much of this loss is unnecessary.

Technologies for Managing Pests

Devising methods of avoiding crop losses has always been a challenge. Early farmers gradually learned to select plants that withstood disease and to use physical methods of reducing losses due to insects and weeds. The simplest method of dealing with both depleted soils and pest problems was to move to new arable land. When that solution was no longer routinely available, the sophisticated and scientific study of crop protection began. Today, as a consequence, methods are available that prevent potentially catastrophic losses due to pests.

However, changes in production systems often favor pests, and new pest strains and pest species appear. These changes in past populations are so great and come so frequently that scientists often are hard pressed to prevent serious reversals in the battle with pests. Frequently, trade-offs must be made among yield, quality, and cost. But to maintain or reach the required level of production, we must develop better systems of managing or controlling pests that do not inflict unnecessary environmental damage and that do not unduly increase costs.

Preventive methods. The most basic of all crop protection methods is prevention, that is, forestalling the introduction and spread of pests. Preventive measures include producing weed- and disease-free seeds, cleaning pest-infested seeds, inspecting nurseries, and using quarantines and regulations to prevent the entry of pests into areas where they do not already exist (*10*).

Quarantine enforcement by inspectors at ports of entry has been highly successful in minimizing the international spread of pests and thus reducing the need for additional control programs. For instance, in the United States in 1974, inspectors found more than 800,000 "dangerous" items in the 60 million pieces of baggage examined. Many of these confiscated items were souvenirs. For example, in 1967, a small boy carried two giant African snails—valued by travelers for their beautiful shells—past inspectors at Honolulu International Airport and released them at his grandmother's home in Miami. The snail feeds voraciously on almost anything green and has a fantastic reproductive capability. In 3 years, Miami had a full-scale infestation that was finally eradicated at a cost of almost $500,000, but the snail did millions of dollars worth of damage before it was eliminated.

The case of the giant African snail demonstrated that the movement of large numbers of people between countries and the increased trade between nations are making effective quarantines increasingly difficult. Consequently, research is under way to find better methods for early detection of pests at ports of entry. Plainly, such preventive pest control must remain an important component of our total strategy and will require increased attention.

Genetic methods. Without the availability of disease-resistant varieties, the high level of production of many crops could not be maintained. Wheat production would be drastically reduced without varieties resistant to rusts. Flax wilt and flax rust are so devastating that flax usually could not be produced if we did not have resistant varieties. Sugarcane and sugar beets in certain areas of the United States have been nearly wiped out on several occasions by insects and diseases.

Resistant varieties that give maximum production of high quality products and eliminate the need to control diseases, insects, and nematodes would appear to be the ultimate answer. Indeed, plant breeders have made enormous contributions to crop protection by developing varieties resistant to specific pests; some examples are wheat that resists stem rust, Hessian fly, and wheat stem sawfly; corn that resists the European corn borer; soybeans that resist nematodes; and rice that resists the striped borer and green leafhopper. Unfortunately genetic methods do not seem to provide a very practical approach to the control of weeds.

Development of resistant varieties is an arduous and complicated task. The breeder must strive to develop one variety that combines high quality; high yield; resistance to several diseases, insects, and nematodes; and the ability to tolerate drought, cold, and other adverse environmental conditions. Such an effort requires long-term research. Moreover, changes occur in pest populations through mutation and adaptation that permit them to overcome resistance in released varieties within roughly the same time required for varietal development. For instance, resistance to plant pathogens is frequently lost within 5 to 15 years.

Another major problem related to the development of resistant varieties is the tendency to increase genetic uniformity during the process of selecting desirable germ plasm. The danger of genetic uniformity was dramatically demonstrated by the outbreak of southern corn leaf blight. In 1970, 80 to 90 percent of our corn crop contained the Texas male sterile (Tms) cytoplasm, which rendered the corn highly susceptible to the T race of the fungus that caused the blight. Now that the danger is apparent, plant breeders are broadening the germ plasm base of many crops to minimize such genetic vulnerability while they continue to develop resistant varieties. Nevertheless, as valuable and desirable as they are, we cannot rely on resistant varieties to solve more than a portion of our pest problems.

Biological control methods. Considerable emphasis is being placed on the development and use of biological methods of pest control, and significant progress is being made (*11*). One highly desirable and classical method of biological control involves the introduction of parasites, predators, or pathogens that are capable of reducing a pest population. Such biological agents have been used against pest insects in 60 countries, successfully in more than 20 cases and with partial success in more than 100 cases (*12*). Also, notable success has been achieved in the control of several weeds, for example, St. Johnswort in the western United States, puncturevine in Hawaii, prickly pear in Australia, and alligatorweed in several parts of the southern United States.

Insect attractants have repeatedly proved their worth in detecting and suppressing pests. For instance, traps baited with attractants for tropical fruit flies are deployed around ports of entry to the United States. Early detection of the Mediterranean fruit fly, the melon fly, and the oriental fruit fly with these traps has saved the taxpayer many millions of dollars in potential eradication costs.

Another method of insect suppression that is especially selective is the release of sexually sterile insects. In the United States, this method is being employed to suppress Mexican fruit flies and pink bollworms and to manage screwworm populations. To be effective, however, the sterilized insects must be released in sufficient numbers to inundate the native population in the target area and buffer zone. Because of its high specificity and cost, the method is applicable only against insects that cause tremendous annual agricultural losses or pose serious health problems.

More biological controls will undoubtedly be developed as a result of the current effort, but these tools too can provide only a part of the crop protection we need.

Cultural and physical methods. Cultural and physical methods are intimately involved in all phases of pest control from the time the plant variety is selected to the time the food is put on the consumer's table. Such methods are generally intended to alter the environment for the benefit of the crop or commodity and, it is hoped, for the detriment of the pests. The factors involved are many and varied—site selection, previous cropping history, seed purity, amount and kind of fertilizer, time of planting, degree of cultivation, irrigation, method and time of harvest, storage, and distribution.

We have achieved considerable success in reducing losses from a number of serious pests by proper use of cultural practices. For example, peanut losses from the stem rot fungus can be essentially eliminated by deep plowing to bury plant debris and by controlling weeds without throwing soil on the peanut plant. The destruction of cotton stalks at a prescribed date after harvest prevents serious losses from the pink bollworm.

Physical methods such as specialized packaging and bioenvironmental manipulation can aid in pest control. For instance, plant viruses have been eliminated from nursery stock by heat treatment. Hot water treatment of wheat seeds controls loose smut. Insect-resistant packaging is now used to protect flour, cornmeal, dried fruits, and other products shipped overseas. Losses due to insects in commercial grain elevator bins can be prevented by using an atmosphere low in oxygen.

Research to improve the effectiveness of cultural and physical methods, which declined with the advent of chemical pesticides, is now being properly reemphasized.

Chemical control. Chemical pesticides continue to provide the primary approach to pest control in most situations. At first the chemical insecticides developed after World War II were so successful that there was some hope they would provide the answer to all pest insect problems. We soon found, however, that some pesticides had undesirable side effects and could not be used indefinitely. Nevertheless, chemical control has many advantages: (i) a wide array of pesticides is available to suppress most pests at practical costs; (ii) pesticides usually act quickly and are effective against high pest populations; (iii) reliable equipment is widely available to apply pesticides; (iv) pesticides permit the individual grower to protect his commodity irrespective of any actions taken by his neighbors; and (v) many pesticides, especially herbicides, can be used selectively.

In the United States agriculture relies heavily on crop protection chemicals to maintain a high level of production. These chemicals are integrated into a production system that includes use of other vital components. Without pesticides it is estimated that the total combined output of crops, livestock, and forests would be reduced by at least 25 percent; the price of farm products would probably increase by at least 50 percent; and we would be forced to spend 25 percent or more of our income for food (*13*). There is, therefore, concern about losing any pesticide that farmers have relied on to protect their crops against pests.

In the foreseeable future, chemical pesticides will undoubtedly remain the primary method of augmenting other controls because without them we cannot maintain present crop production, or more important, increase it. Meanwhile, we must continue the search for more effective pest control methods and for new approaches that will reduce crop losses and costs—in money and in effect on the environment.

Integrated systems. The best strategy for controlling most pests is the coordinated use and management of many technologies, including preventive measures, resistant varieties, pesticides, biological agents, proper cultural practices, crop rotation, sanitation, and specialized chemicals such as attractants and growth regulators. The proper combination can give maximum control of pests during both crop production and marketing and can also minimize the impact on nontarget organisms.

When technologies are integrated for pest management, interrelationships among pests, hosts, and the environment are considered, and different approaches may be required in different localities or even in adjacent fields. For example, effective integration of tillage methods, herbicides, and crop cultivation will suppress the pernicious yellow nutsedge in fields that are to be planted with soybeans, alfalfa, and other crops. In other situations other factors become important. For example, to control the golden nematode of potatoes, the grower can use nematicides, resistant varieties, and crop rotation. The decision he makes should take into account other pest problems that may occur and the way in which the control measures will synchronize with other production inputs.

In pest management the timing of pest control practices depends on the particular kind of pest involved. With mites, for example, treatment should be delayed until the insect has reached, or is about to reach, an economically damaging level. With diseases such as late blight of potato and brown rot of peach, preventive treatments must be used to avoid serious damage. At all times care must be exercised to avoid unnecessary buildup or overuse of any pesticide that might result in excessive damage to beneficial organisms or to the environment.

Likewise, a combination of methods can be used to prevent damage to stored food products. Physical barriers can prevent rodents, birds, and insects from reaching the stored products. Storage moisture, temperature, and atmosphere may be manipulated to prevent fungal or bacterial spoilage. These nonchemical methods can also be integrated with use of pesticides.

Future approaches to pest problems must surely include increased research to develop and improve many kinds of technologies. The basic aim is to develop suitable combinations to achieve the desired control, reduce economic losses and the costs of control, and increase the safety of man and the environment.

Environmental Interrelations

When man began converting land to the intensive production of agricultural crops, a sequence of events occurred that altered both plant life and populations of other organisms. For example, weeds, insects, diseases, nematodes, pest birds, rodents, and other organisms often find conditions much more favorable for their existence where specialized crops are grown in large areas.

The pests that attack crops and food products have evolved over the centuries. Many vary from one part of the world to another, a few appear to be universal. However, populations of pests are dynamic, have great capacity to reproduce and survive, and are capable of adapting to great changes in the environment. Thus, attempts to manage or control pest populations are often thwarted by some change in the organism as it adapts to a new situation. For example, new races of stem rust evolve to attack resistant varieties of wheat; insects or fungi develop that are resistant to a pesticide used too exclusively; and weed populations shift until weeds susceptible to a particular control method are replaced by species that require a different method of control.

There are also important interrelations between production inputs and pest control. For example, pest problems sometimes intensify as the amounts of fertilizer and water and the extent of cropping are increased. In India, rice crops were more extensively damaged by the rice hispa beetle in fields where nitrogen was applied than in unfertilized fields. In Arkansas, uncontrolled barnyardgrass reduced yields 50 percent in fertilized rice fields, compared with 25 percent in rice fields that had a low level of fertilization. Use of herbicides can reduce the tillage required for weed control and so can save energy, conserve water, and reduce soil erosion. Yet, this type of weed control and production system can encourage the development of new insect and disease problems that require a new pest management system.

Plainly, environmental changes will occur as we work to protect against pest losses. The changes must be properly balanced against the benefits of the pest management techniques employed.

Actions to Reduce Losses

Since more food will be required to meet worldwide demands in the future, we must turn to double cropping, increased use of fertilizers and irrigation, planting large acreages to individual crops, and use of high-yielding varieties and effective pesticides. Such intensification will inevitably increase crop protection problems. For example, the rice whorl midge was not a significant pest in the Philippines until irrigation and continuous cropping of rice became a common practice (*14*). Now this insect causes yield reductions up to 25 percent. Our success in providing necessary food supplies hinges on our ability to cope with pest problems of this type.

In our opinion, effective integration of pest control technologies into efficient production systems could significantly increase world food supplies. However, implementation would require the cooperation of multidisciplinary scientific groups, public agencies, growers, and commodity organizations and would involve efforts in all areas —from basic research to development to practical use by farmers and ultimately to delivery of food to consumers. In the United States, the weakest link is in the development phase (Fig. 1). Farmers have been the integrators of new technologies into all phases of crop production. Fortunately, some have been highly successful, but many others could make improvements if they had more adequate information about the way a total system works when all components are integrated. This type of information would be especially helpful in guiding farmers of the developing countries toward improved methods of reducing losses due to pests.

If farmers are to broadly adopt a system of pest management, they must first be convinced that they will gain by using it. Public and private agencies

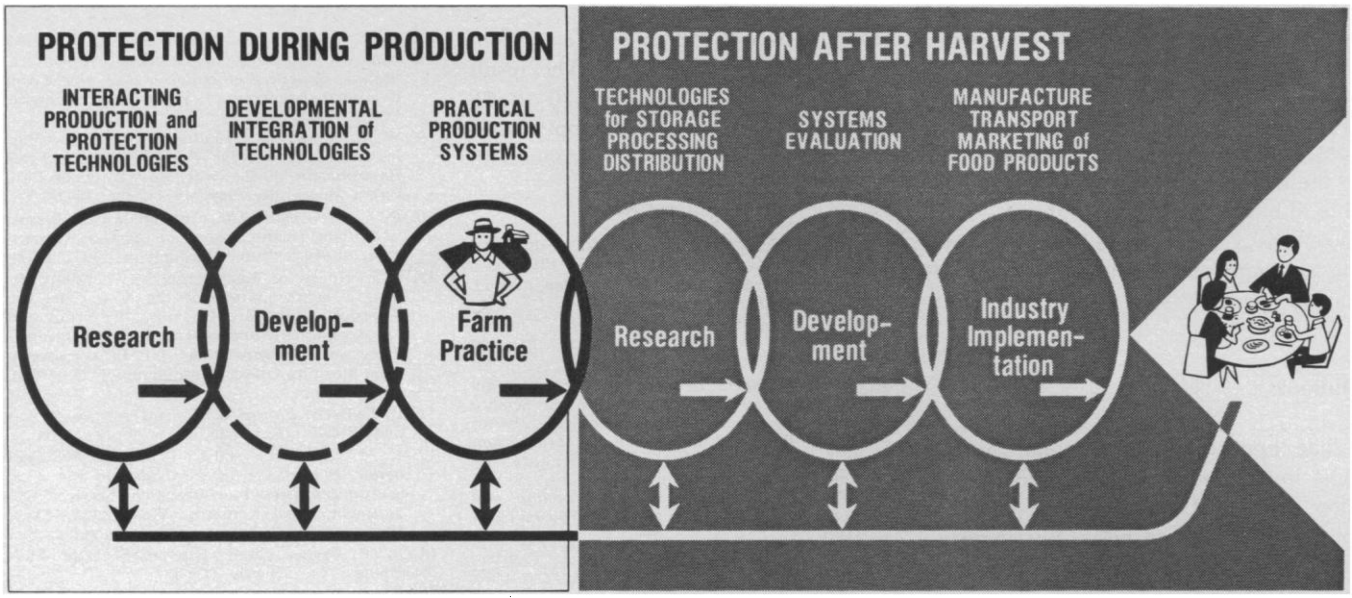

Fig. 1. Better use of technology insures more food.

are therefore challenged to generate cost-benefit information on which the grower can base a decision about the pest control methods and approaches he should use. This information can be developed through research and by practical pilot tests on farms. For example, a concerted effort was begun in the United States in 1972 to use pest management principles more effectively in crop production programs. The initial emphasis was on insect control, and the program involved a research phase, pilot testing of control methods, and implementation of the most promising technologies by growers. Several federal and state agencies, grower organizations, and others were involved, and a total of 39 practical application projects were initiated in 29 states on 15 crop commodities.

One of these practical application projects, an insect management project in California, is evolving into a complete crop management program for cotton (*15*). The program is administered by the California Agricultural Extension Service, who share the operating responsibility with private pest management consultant firms. The total program encompasses such factors as irrigation; application of fertilizer; vegetative and fruiting development; and extent of insect, disease, and weed infestations. A data handling and retrieval system was developed to facilitate analysis of pest problems and crop management practices. Thus, growers can keep careful watch on the development of the cotton plant and can make management decisions based on physiological needs rather than on the calendar. The success of the approach is indicated by increased grower participation and by the interest of private consulting firms and the farm chemicals industry. The program is now financed primarily by growers.

In Michigan, another pilot program emphasizes management of the major disease, insect, and mite pests in the apple ecosystem (*16*). It was initiated in 1972 by the Michigan Cooperative Extension Service. The program was initially funded completely by federal and state agencies, and the apple industry is increasing its financial commitment every year. By the 1978 growing season, the program is expected to be largely financed by the growers. Environmental factors, including temperature, rainfall, humidity, and leaf wetness, are monitored through the growing season. Pest populations are monitored by using spore traps to detect apple scab spores, pheromone traps to detect specific insects such as the codling moth, selective media to determine the potential for fire blight infection, and bait traps to detect apple maggots. Orchard scouts assist in the monitoring and make weekly inspections to assess the status of the control programs. Populations of predatory and destructive mites are determined from leaf samples, and population ratios are used to determine whether control is necessary. A computer stores information and predicts pest development. Automatically answered telephones are used to give pest-development information to the growers and suggest control measures. This program resulted in a significant change in the pest control practices used by a majority of the participating growers and a saving of approximately $600 to growers who altered their control program.

Similar effective implementation of integrated pest management systems for plant diseases, nematodes, birds, rodents, weeds, and insects, although essential, will be difficult. Undoubtedly, governments must usually provide the leadership in organizing programs designed to demonstrate the best use of available technologies for production of crops and for their protection both before and after harvest. However, some countries may not have the immediate capability to utilize complex production systems, and techniques must be developed that are compatible with the level of technological skills and resources available.

Multidisciplinary teams should be assembled and suitable management structures established to plan, coordinate, and implement the desired programs. For example, crop protection teams could be created to develop pest control systems that would meet the requirements of different agricultural areas and regions. The proposed system would have to be evaluated for efficacy, economic impact, risks and benefits, and general applicability to the farming system. In the lower Mississippi Valley of the United States, for instance, the focus should be on production and protection systems for cotton, corn, soybeans, and rice, and the team would include 8 to 12 scientists (from disciplines such as entomology, plant pathology, wildlife biology, nematology, weed science, engineering, biostatistics, and economics). Whatever form of pest control is adopted, it must yield a profit to the farmer and must have no intolerable ill effect on the environment. Also, society as a whole should gain by having an increased supply of wholesome food.

Outlook

The opportunities are great for almost immediate improvement of world food supplies if we set about reducing the annual losses to pests. But there is little hope of substantially reducing these losses unless reduction becomes a high-priority goal of national governments. We believe that losses could be substantially reduced—perhaps 30 to 50 percent—by making better use of technologies currently available. The result could mean an increase of 10 to 15 percent in the world food supply without bringing new land into production.

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Soils of the Tropics and the World Food Crisis

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The term "tropical soils" evokes widely different thoughts in specialists and scholars from several disciplines. Overgeneralizations about soils of tropical areas have led to many misconceptions about the potential of the tropics for food production. Much has been learned in the past two decades about the properties and management of such soils. Our purpose in this article is to outline the salient properties of soils in the tropics and the role of these soils in world food production.

Tropical soils can be quantitatively defined only as those soils which lack a significant summer to winter temperature variation; that is, the difference between the mean summer and mean winter temperature at a depth of 50 centimeters is less than 5°C (*1, 2*). Aside from this, the range of conditions responsible for soil formation is as diverse in the tropics as in the temperate regions. Rocks, the parent material of soils, are the same in both regions. Erosional and depositional patterns are not markedly different between the two geographic regions. In both tropical and temperate regions, the time of soil formation on any geomorphic surface may range from yesterday on floodplains or fresh volcanic ashfalls to undetermined antiquity on more stable surfaces. Arid and humid, hot and cold climates exist in both zones. The term "tropical soils," therefore, is as meaningless in conveying most soil properties as its corollary, "temperate soils."

Although soil formation in tropical areas is not different in kind from soil formation in the temperate zone (*3*), the areal magnitude of certain soil-forming patterns is significantly different. Much of the northern temperate zone has had its surface reworked by Pleistocene glaciation and carpeted by thick loess mantles. These processes have influenced the age of the soils and added an influential silt-sized component (2 to 50 micrometers) to the parent material that is frequently absent in tropical areas. Many more soils in the tropics have been formed from material that has been reworked since the Precambrian by the processes of surface erosion and deposition, which intensively weather the material. Although the areal extent of recent volcanic ash deposits is greater in the tropics, there is a larger proportion of relatively younger soils in the temperate region.

Generalizations beyond these statements begin to lose accuracy. The statements that laterite and lateritic soils are prevalent in the tropics and that tropical soils have low organic matter contents are two generalizations that have tended to hinder understanding of tropical soil conditions.

The Laterite Exaggeration

Probably no greater misunderstanding about soils exists than the concept that there is a uniquely tropical soil-

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