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Agricultural Development and Environmental Research: American and Czechoslovak Perspectives

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South Bohemian Biological Center
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Editors

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Preface

A bilateral workshop jointly sponsored by the National Academy of Sciences (NAS) and the Czechoslovak Academy of Sciences (CSAV) was held in Czechoslovakia April 6-16, 1987. Entitled "Agricultural Development and Environmental Research," the workshop was the first to be held within the framework of the NAS-CSAV interacademy exchange program begun in 1966. Dr. Charles E. Hess, Dean of Agricultural and Environmental Sciences at the University of California, Davis, and Academician Vladimír Landa, Director of the CSAV South Bohemian Biological Center and a member of the Presidium of the Czechoslovak Academy of Sciences, served as workshop co-chairmen. A full list of participants appears in Appendix 1.

The workshop sessions were held in České Budějovice at the CSAV South Bohemian Biological Center. Because of heightened awareness of the possible environmental consequences of increased agricultural productivity, the workshop discussions were lively and covered a wide variety of topics. The diversity of these topics is reflected in the following partial list of research priorities identified by workshop participants:

- Development and application of systems analysis techniques in managing natural and altered ecosystems;
- Investigation of nutrient transformations and losses in ecosystems;

- Development and application of exposure assessment techniques, including estimating human exposure to pesticides and other toxic chemicals;
- Development of techniques for minimizing waste generation;
- Expansion of research on genetic engineering to develop plant species resistant to diseases and pests;
- Investigation of interspecies relationships in weed/crop systems as a basis for reducing herbicide use;
- Increased understanding of the biology and microstructure of soils;
- Determination of effects of acid deposition on biological systems.

The complete list compiled at the workshop of research problems and priorities, as well as of possible themes and modes for cooperation, appears in Appendix 2.

After the workshop, further discussions were held between American and Czechoslovak specialists during associated visits to collective farms at Chelčice and Slušovice and to various governmental and research institutions in Prague and Bratislava. A complete list of visits appears in Appendix 3. The workshop and visits served to stimulate interest in future bilateral collaboration in the agricultural and environmental sciences.

The NAS expresses its appreciation to the Czechoslovak and Slovak Academies of Sciences (SAV) for organizing the workshop. Financial support from the Rockefeller Brothers Fund and the Ford Foundation is also gratefully acknowledged.

The views expressed in the individual presentations which follow are those of the authors and do not represent the views of any official organization or agency.

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Main Issues of Agriculture and the Environment and the Strategy of Agricultural Development

ALOIS SLABÝ
Czechoslovak Ministry of Agriculture and Food

The advanced tradition of Czechoslovak farming is evidenced by the long-term development of agriculture in Czechoslovakia. Within the European region, Czechoslovak agriculture has always ranked high in the use of modern and progressive farming methods and in the education of the farming population. Agricultural cooperatives have a tradition of more than one hundred years in Czechoslovakia, and this tradition has continued during the formation of large-scale, socialist, agricultural production organizations which began in 1949.

The bulk of agricultural production in Czechoslovakia comes from the socialist sector, including state farms and cooperative farms. The socialist sector farms on 95.9 percent of the area of arable land. Of this, 30.9 percent of the area belongs to the state farms and 65 percent to the cooperatives. Individual farmers and keepers of small plots of land use about 4.1 percent of the available farm land. The total area of farm land in Czechoslovakia is 6,794,000 hectares, including 4,786,000 hectares of arable land (70.4 percent of the total).

As of January 1, 1987, Czechoslovakia had 1,664 cooperative farms with an average size of 2,584 hectares and 162 state farms with an average size of 8,579 hectares of farm land, although their sizes vary considerably. For instance, cooperative farms range from about 1,000 hectares to almost 10,000 hectares in exceptional cases. State farms range from about 2,500 hectares to almost 70,000 hectares, which is the size of several state farms in the border regions of the Czech Socialist Republic. There are also narrowly specialized units called Joint Agricultural Enterprises. It is interesting to compare these data with data from the initial period before the socialization of agricultural production almost 40 years ago. At that time the land in the territory of Czechoslovakia was farmed by 1.5 million small farmers on 33 million plots.

Agricultural production is also influenced by the industrialized nature of the Czechoslovak territory, by the density of settlements, and by water management conditions with the majority of waters flowing away from the territory of the country. The high degree of afforestation in Czechoslovakia is a positive feature with regard to agriculture, as forests cover about one-third of the territory. Great progress has been made in the concentration and specialization of agricultural production. This approach provides good opportunities for the utilization of the results of scientific and technological development and for advanced economic activity of agricultural enterprises.

Czechoslovak authorities pay great attention to the development of agriculture and food production and continuously create favorable conditions for further intensive development of this important part of the national economy. Czechoslovak agriculture, and consequently the food industry, have recently undergone substantial changes. As a result of effective intensification, agricultural production has increased considerably, and the domestic food market has been significantly enriched. Retail trade networks are fully supplied with a wide spectrum of food products.

The results achieved in agriculture provide a good basis for high per capita food consumption. In 1986 per capita consumption levels were above 86 kg for meat, 250 kg for milk and dairy products, 9 kg for butter, and 344 for eggs. Self-sufficiency in temperate zone products is almost 98 percent, while self-sufficiency in meat and other animal products, sugar, potatoes, and cereals has reached 100 percent in the last two years.

The material and technical base for agriculture contributes significantly to the results obtained. Czechoslovak enterprises now have 140,000 tractors, 50,000 trucks, and 20,000 grain combines. Of course, the high qualifications of the agricultural workers is also important for achieving good results. At present 900,000 persons are permanently engaged in agriculture: 35,000 are university graduates, 105,000 have secondary level education, and 320,000 have left school to become apprentices in agriculture. Future objectives for agriculture in Czechoslovakia include full self-sufficiency in temperate zone products, improvement of quality of an expanded assortment of food products, and improvement of the overall effectiveness of agricultural production.

Czechoslovak authorities pay extraordinary attention to the relationship between further intensification of agriculture and environmental conservation. Agricultural activities are conducted on more than 52 percent of the territory of the country, and a sound environment is considered to be an inseparable part of the standard of living. The concept of a balanced relationship between further development of agriculture and protection of the environment includes the following three major tasks:

- Securing and developing the positive influence of farming on landscape ecosystems, referred to as the "non-production function" of agriculture;
- Protecting the environment against potential adverse effects of farming and food processing industries, primarily caused by failures to adhere to technological discipline;
- Minimizing the limiting effects of the environment on agriculture and food, both qualitatively and quantitatively.

To conserve the agricultural land fund in Czechoslovakia, legal regulations were adopted in the early 1980s. As a result, losses of farm land have been markedly reduced, and increased attention is being paid to the productivity and quality of the soil. Agricultural workers and responsible authorities currently take appropriate measures for maintaining the quality of surface waters. The purity of air is a local agricultural problem which will require changes in the structure of production, and research is currently being conducted in this regard.

Special interest is devoted to the use of chemicals in agriculture. All chemicals to be used—both domestic and imported—are tested, and state authorities grant permission for their use on the basis of test results. Methodological instructions for safe utilization of agricultural chemicals are issued annually.

Strict and systematic measures are also taken to control and maintain the quality of food from the point of view of human health. The institutions responsible for this activity include the Central Agricultural Controlling and Testing Institute, the State Veterinary Administration, and the State Inspectorate of Farm and Food Product Quality. These problems are of great interest to scientists engaged in both basic and applied research.

Agriculture and food production as a branch of the national economy has its own *Conception of Environmental Conservation and*

Development and Rational Natural Resources Utilization, a document which is to be in force until the year 2000. The concept represents a unified plan for further intensification of agriculture while outlining a complex system of measures to secure a balanced relationship with the environment. In this connection, emphasis is placed on the role of science in an effort to cope with the global and local problems of effective and reliable environmental protection. Intensive agricultural production is confronted with these problems at the present time and, owing to the development of what is called the civilization factor, will also have to face them in the future.

A Conceptual Framework for Analyzing Agricultural and Environmental Concerns

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U.S. Department of Agriculture

MAJOR ISSUES IN AGRICULTURAL DEVELOPMENT AND ENVIRONMENTAL RESEARCH

A major requirement for the long-term stability of civilization is a dependable supply of food, feed, and fiber. Agricultural systems developed over wide ranges of climate and soil resources have achieved remarkably high levels of production of food, feed, and fiber to provide relative security for an ever-increasing world population. With few exceptions, high levels of production are achieved by bringing agronomic practices into harmony with natural processes of the biosphere.

Global and regional patterns of distribution of energy and water are the overriding controls on biological processes essential for agricultural production. Availability of essential nutrient elements imposes the next level of control, but the use of fertilizers has largely removed or mitigated this limitation. However, levels of fertilization which are out of balance with other processes can result in both short- and long-term adverse effects on the environment and soil productivity. The challenge to modern agriculture is to develop optimum balances between inputs and outputs of production systems, while also providing a basis for continued increases in productivity with minimum adverse effects on the environment.

The following issues are of major concern for both agricultural productivity and environmental quality:

- soil erosion;
- sedimentation, salinization and sodification;

- water soluble pollutants;
- soil organic matter loss;
- toxic substances;
- genetically engineered organisms;
- climatic change resulting from increasing concentrations of trace gases and CO_2 in the atmosphere.

Agricultural and environmental issues are related and can be analyzed using a common conceptual framework. An appropriate framework should integrate processes of energy flow, nutrient cycling, and mass transport into a quantitative description of system function. In its simplest form, this approach involves determining the energy and mass balances of water and materials in a unit of land and determining rates and controls for the transformations in this unit. The mass balance of any component involves inputs, outputs, and changes in storage within the system. Major outputs are those to stream water and groundwater, to the atmosphere, and in harvested products. Thus, management of agro-ecosystems aims to maximize crop yield per unit input while minimizing losses from the system.

A more complete understanding of the interactions of units of soil with their environment at appropriate temporal and spatial scales is needed. The question of scale must be addressed to solve long-term and large-scale agricultural and environmental problems. Because of new technologies, regional- and global-scale questions can now be addressed. These technologies include remote sensing, computerized data management systems, analytical and monitoring equipment, chemical and biochemical techniques and, perhaps most importantly, systems analysis.

CONCEPTUAL FRAMEWORK

Early conceptual models of ecosystems developed by Dokuchaev and Jenny emphasized the factors controlling development of soil properties, referred to as *state factor controls*. These have been extended to include key processes of flows of energy and matter to provide integrating structures for analysis of ecosystem dynamics. The relationships among driving variables (controlling factors), key processes, and ecosystem properties and structure are shown in Figure 1. Driving variables are externally imposed variables little affected by the state of the ecosystem.

Important ecosystem processes include primary production, decomposition, and nutrient cycling above and below the ground. Heat

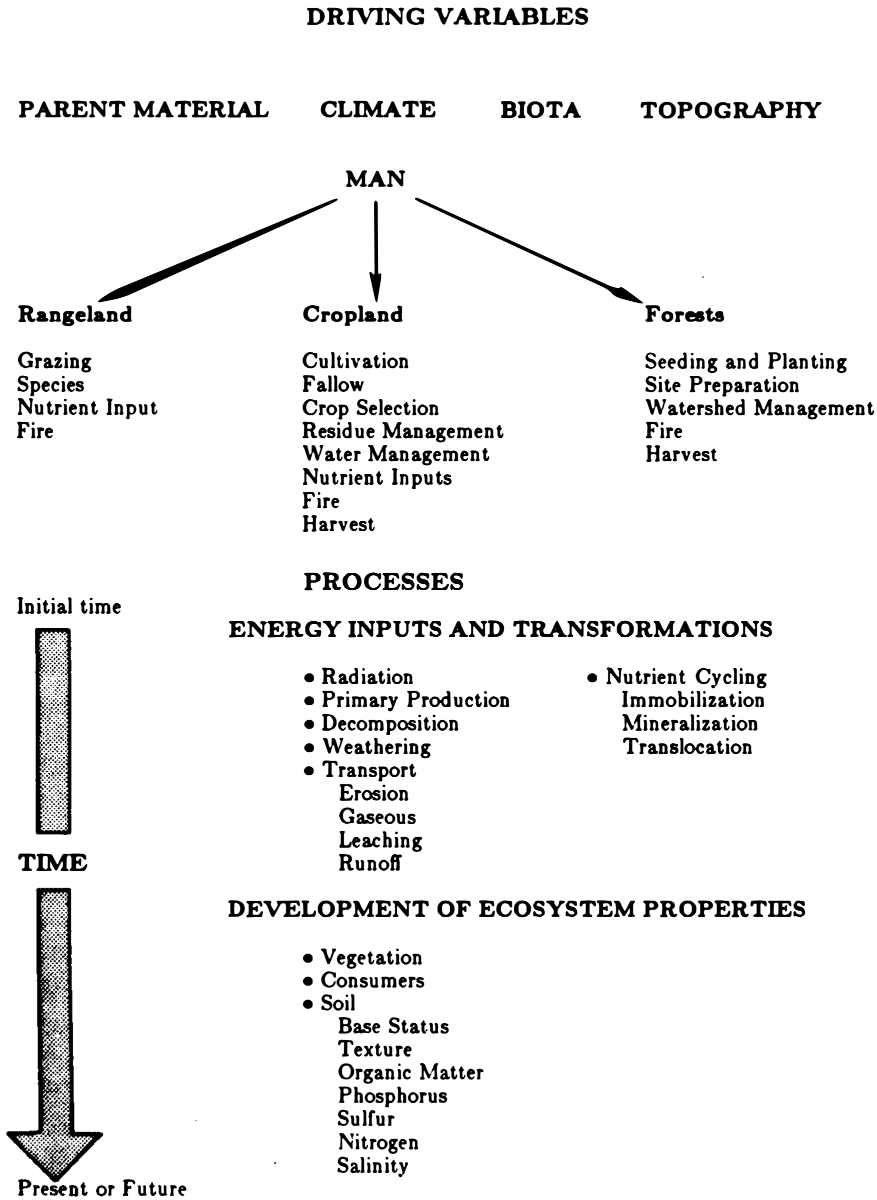

FIGURE 1 Relationships among driving variables, processes, and ecosystem properties.

and water play key roles through their effects on the rates of biological and chemical processes. The rates of ecosystem processes determine the rate and direction of change of ecosystem structure, i.e., the composition of the biota. Ecosystem structure, in turn, has feedback effects on the rates of processes. The general hypothesis is that driving variables control the rate and direction of processes that determine the properties of an ecosystem. Specific hypotheses involve the particular effects of driving variables on various processes and thereby on the dynamics of ecosystem structure over time.

This approach requires a thorough understanding of processes over a wide range of controls. It is assumed that the same suite of processes are operative over a wide range of systems and that it is controlled by the state variables that regulate their expression in a given system. In this context the biogeochemistry of carbon, nitrogen, sulphur, and phosphorus provides linkages between processes and ecosystem properties.

The effects of controlling factors are expressed and observed across a wide range of spatial scales from global down to regional, landscape, and field levels. Process controls are also documented across a wide range of scales of time, ranging from hours and days for microbial and plant growth processes to years and centuries for the development of steady-state levels of organic matter and pedogenesis. Information on the nature of process controls and the interactions of biogeochemical cycles provides linkages across various levels of investigation and has stimulated integrated approaches to analysis of both natural and agricultural systems.

BIOGEOCHEMICAL CYCLES

The transformations and gains or losses of key nutrient elements provide valuable diagnostics for analysis of changes in both natural and man-managed ecosystems. Examination of changes in elemental forms and concentrations in organic matter of soils developed along environmental gradients have given insight into interrelationships between carbon (C), nitrogen (N), sulphur (S), and phosphorus (P). Changes in C, N, and P show the close linkages between organic C and N in mature soils and P content in the original parent material (Cole and Heil 1981). Thus, given sufficient time, the supply of N comes into balance with the supply of P (assuming S is not limiting). Microbial growth processes are the principal arenas for the adjustment of the supply of N to the supply of P.

Although carbon transformations closely track energy fluxes, knowledge of carbon flows has limited value in predicting nutrient flows since each nutrient has specific reactions and storage compartments which must be considered. Flows determined for C are not directly transferable to N, nor are those for N the same as those for S or P. The mechanisms stabilizing organic C, N, S, and P are not necessarily common to all four elements. A dichotomous system in which N and parts of soil-S are stabilized as a result of direct association with soil-C has been proposed (McGill and Cole 1981). These forms mineralize as the result of C oxidation—classical biological mineralization—to provide energy. Sulphur and P in the form of esters, on the other hand, are stabilized directly by interaction with mineral components and are mineralized by enzymes in response to the need for a specific element. This latter process is called *biochemical mineralization* since it operates largely outside the cell. These concepts account for variability in soil organic matter composition and set the stage for predicting the relationship between the cycling rates of N, S, and P in soils. Since the behavior of S is intermediate—between that of N and P—a study of S transformations helps to explain differences in quality of soil organic matter. These elemental interactions need to be integrated with other concurrent pedogenic processes such as mineral weathering and leaching.

The complex interactions of chemical and biochemical processes involved in nutrient cycling are illustrated by the conceptual model of phosphorus dynamics in a soil/plant system shown in Figure 2. Primary P minerals are slowly dissolved during weathering processes providing phosphate ions that enter into the solution P pool (Smeck 1985, Stewart and Sharpley 1987). Soil solution phosphate ions are shown to be in equilibrium with a quantity of labile inorganic P (P_i) such that in any one soil the ratio of labile inorganic P to solution P maintains a constant ratio over the normal range of P concentration found in cultivated soils. A portion of the solution P will be precipitated as secondary P minerals and eventually converted to occluded or unavailable forms in more weathered soils.

Plants take up phosphate ions from the soil solution, and the dynamics of P uptake are well researched (Barber 1984). The depleted solution P pool is immediately replenished from labile and moderately labile P_i forms. If these pools are depleted, less soluble species such as secondary P minerals regulate the solution P concentration.

Uptake of solution phosphate by bacteria and fungi stimulated by the addition of microbial substrates such as litter and crop residues,

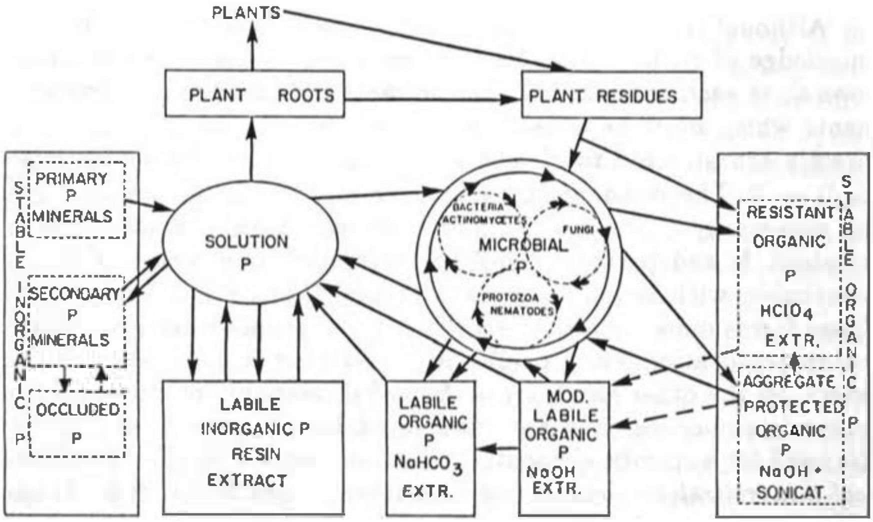

FIGURE 2 Conceptual model of phosphorus cycling in soil plant systems. (Source: Stewart, J.W.B. et al. 1983)

and release of soluble phosphate ions (P_i) and labile and stable organic (P_o) forms are represented in Figure 2 as a revolving wheel to emphasize the central role of the microbial population in P cycling. When microbial cells are ruptured or lysed, a variety of organic and inorganic P compounds are released to the soil solution which react with inorganic and organic soil components to form P_i and P_o compounds of differing solubility or susceptibility to mineralization. The rate of mineralization of P_o forms depends largely on phosphatase activity which, in turn, can be controlled by solution P concentration (McGill and Cole 1981). Stable P_o accumulates in both chemically resistant and aggregate protected forms.

Organic P existing in chemically or physically protected forms may be slowly mineralized as a by-product of overall soil organic matter mineralization or by specific enzyme action in response to the need for P. Therefore, organic matter turnover as well as solution P_i concentration and the demand for P by microbial and plant components will be factors controlling the lability of P_o (McGill and Cole 1981). A continuous drain on soil P pools by cultivation and crop removal will rapidly deplete labile P_i and P_o forms.

In summary, the P cycle is a system in dynamic equilibrium with interchanges governed by chemical, physical, and biological reactions. Microbial activity is depicted as a wheel rotating in the soil in response to energy, particularly C inputs, and having a central role in P transformations. Should the wheel be stopped or slowed down by lack of C inputs, the supply of P to plants will be limited to the quantity of labile P_i. If the wheel is operating, then the plant is supplied with a larger quantity of labile P as solution P is constantly being replenished from labile P_i and P_o forms. Over a longer timescale these same processes operate to evolve major changes in amount and forms of phosphorus in soils across toposequences and chronosequences (Smeck 1985).

Similar conceptual models have been developed for other major nutrient elements (Follett et al. 1987). Simulation models are being developed to integrate information on nutrient and organic matter dynamics with information on all other factors controlling the functioning of complex natural and managed systems.

REGIONAL ANALYSIS OF SOIL ORGANIC MATTER, NUTRIENT AVAILABILITY, AND SOIL PRODUCTIVITY: THE GREAT PLAINS

A study of management effects on soil organic matter and productivity in the semi-arid Great Plains of North America exemplifies the application of this conceptual framework. The accumulation of organic matter in grassland soils over a wide range of temperature and moisture gradients in the Great Plains is an excellent example of state factor controls on development of an important ecosystem property. Soil organic matter is a key indicator of soil quality as it affects nutrient availability, soil stability, and susceptibility to erosion. Organic matter levels reflect past management history.

Regional-scale investigations of nutrient and carbon dynamics in agricultural ecosystems have been conducted since 1979. The objectives of the research are to:

- evaluate past, present, and future management practices with respect to their impacts on soil organic matter in the Great Plains, and to understand key processes of organic matter formation in semi-arid soils; and
- develop the capability to predict the effects of management and climatic changes on organic C, N, S, and P across the Great Plains, with projections to similar soil/climate zones around the world.

The dynamics of soil organic C and N in cultivated and grassland systems were simulated with a mathematical model which successfully represents the long-term impact of cultivation on soil organic matter C and N levels for a wheat fallow system, and simulates the impact of different combinations of straw, manure, and N addition in Swedish soils. A later version of this model simulates the dynamics of C, N, S, and P in the soil and plant system. It includes the controls of plant lignin content and soil texture on nutrient cycling and soil organic matter levels.

This model has been used to simulate steady-state organic matter, plant production, and decomposition levels for grassland soils across the climatic gradients of the Great Plains region. It has also been used to simulate cultivation effects on N, P, and S availability over the long term in Canadian wheat fallow systems and the impact of different fire frequency on C, N, and P dynamics in a native tallgrass prairie.

Rangeland productivity was evaluated using data collected by the U.S. Soil Conservation Service for 12,000 range sites, and soil properties were examined from chemical characterization of 1,000 pedons. These data were combined with climatic data for regression analysis, yielding regional maps of productivity and organic matter levels illustrated in Figure 3.

The analysis of changes in levels of organic C, N, S, and P in grassland soils placed under cultivation confirmed concepts of state factor control over soil processes that were developed in early studies of topo- and chronosequences formed over geological time periods. Major controls on key chemical, physical, and biological processes were identified to provide linkages for interpretation across different scales of time and space.

The systems analytical approach is presented as a tool for organizing and integrating information on key chemical, physical, and biological processes fundamental to the understanding of changes in natural and managed systems. When quantified with the use of mathematical simulation models, this approach enables prediction of management effects on productivity and the potential for adverse environmental effects.

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Helpful discussions with Dr. John Stewart, Director, Saskatchewan Institute of Pedology, during preparation of this paper are gratefully acknowledged.

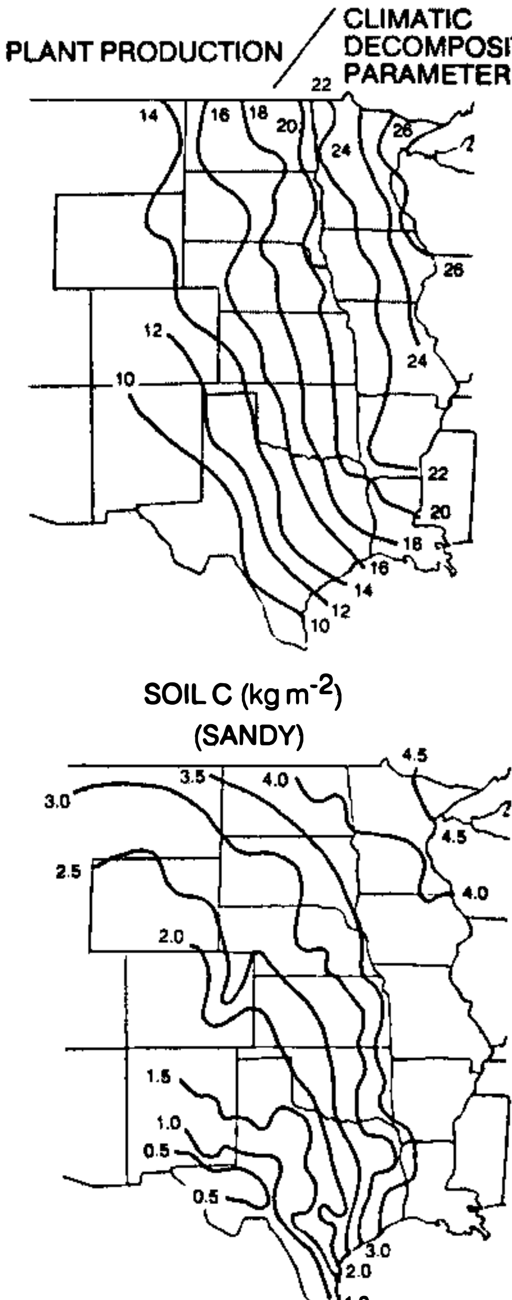

FIGURE 3 The upper panel shows the ratio of productivity (NPP) to the climatic decomposition parameter (CDP). This parameter integrates the effects of temperature and moisture on heterotrophic activity. The ratio NPP/CDP indicates the potential for carbon stabilisation in the soil. The lower panel shows predicted soil carbon levels to 20 cm for sandy-textured grassland soils.

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Landscape Ecology as a Science

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Formation of an adequate theoretical-methodological basis is a necessary precondition for more effective management of landscape utilization. The aim is to satisfy the ever-rising needs of society while respecting ecological limits, resource conservation needs, and the maintenance of landscape values. In this sense, a key role is played by landscape ecology. However, landscape ecology has not always been able to keep pace with the development of research objectives, and the movement from definition to evaluation and prediction seems to be rather slow. The following proposed approach should contribute to a better evaluation of landscape stability since ecological research should concentrate on system relations, linkages, and interactions.

ANTHROPOLOGICAL/ECOLOGICAL LANDSCAPE SYSTEMS

From the ecological viewpoint, a landscape is a system unit of mutual relationships, linkages, and interactions of particular subsystems or components, including the biosphere or geobiosphere, the technosphere, and the sociosphere (Figure 1). Interactions in a landscape are mostly induced by man and can therefore be defined as an anthropological/ecological landscape system (AELS) (Hadač 1977).

The particular linkages, relationships, and interactions within the AELS shown in Figure 1 can be attributed to an adequate approach in levels of recognition. Recognition of these internal and inter-system relationships is characteristic of the classical scientific disciplines such as geology, botany, sociology, biology, and ecology.

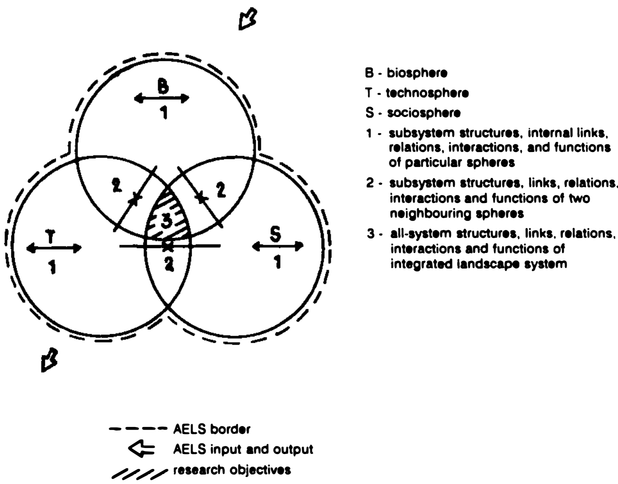

FIGURE 1 Anthropoecological landscape system.

However, such knowledge cannot be easily synthesized to evaluate all-system relationships, linkages, and interactions within the AELS.

Biological ecology traditionally addresses the anthropogenic elements, and indeed all components of disturbances of the biological condition of organisms, species, communities, or ecosystems (Odum 1977, Dajoz 1972). Landscape ecological research should regard these anthropogenic elements and their components as equal in importance to other landscape elements and components.

A geo-ecological site (GES), which is an element of AELS, has its specific structure and processes. At the horizontal level it is characterized by a relatively homogeneous biocenosis or technoanthropocenosis. At the vertical level a GES occupies the soil under the influence of the rhizosphere and/or the technosphere and the part of the atmosphere which participates in the energy/material processes taking place within the particular GES.

Landscape parts called subsystems are considered to be higher AELS units, and they consist of geo-ecological site complexes with single prevalent uses. These complexes of particular subsystems in turn constitute landscape systems or AELS segments. The AELS structure is shown in Figure 2.

All-system linkages and relationships are based on manifestations of lower order interactions of the components and elements, their structures, and processes. However, they are not merely a sum of these lower order interactions; they create a new entity. The manifestations of the all-system relationships within AELS result in the stability or non-stability of the total AELS. Therefore, the ability of AELS to maintain stability or to acquire a state of non-stability depends on the all-system relations.

Stability exists at the level of particular landscape subsystems or elements. For example, at the biosphere level, there is species, population, cenosis, and ecosystem stability. Similarly, we can speak about partial stability at the level of the technosphere or the sociosphere. Non-stability at the level of components and elements need not necessarily imply non-stability at the all-system level. Nevertheless, the stability of sociosphere and technosphere components depends on the stability of biosphere components. On the other

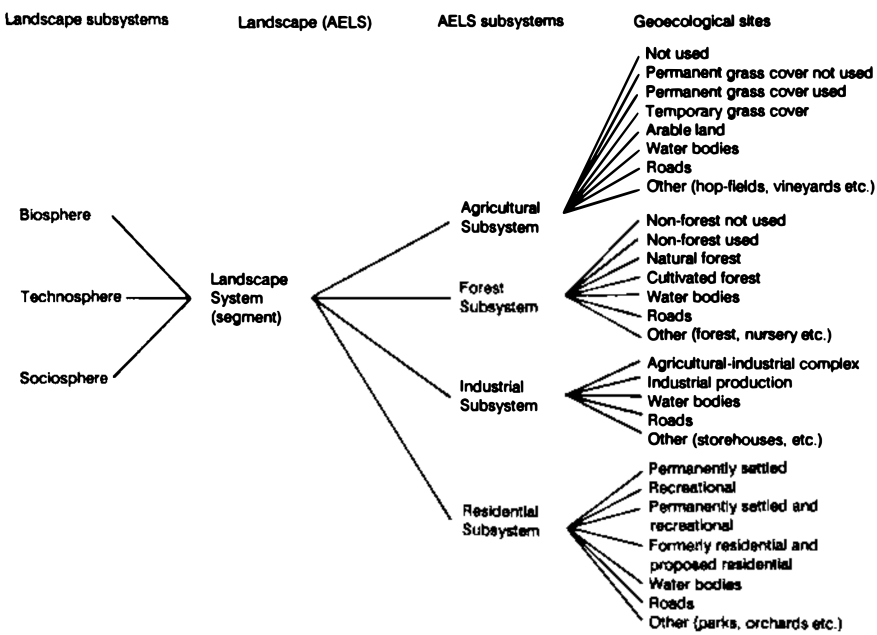

FIGURE 2 Anthropoecological landscape system structure.

hand, as mentioned above, the sociosphere and technosphere are the determining factors within the AELS.

Landscape system stability is the ability to maintain an equilibrium state when the system is not being disturbed (persistence), to resist particular load rates (resistance), or to return to the original equilibrium state after having been disturbed (resilience). The rate of landscape system disturbance depends not only on the strength of the impact but also on its character and type, as various impacts cause different responses. On the other hand, the response to the same type of influence can differ according to the type of landscape system (Hadač 1977).

It has been proven that natural system stability increases with development of the basis of the system due to self-organizing processes (Miles 1979). For example, a climax community is an open system with stabilized matter and energy flows. However, this can be applied only to the natural parts of the biosphere. In the case of the AELS, only man can be regarded as the organizing element of AELS stability by making maximum use of the self-organizing biosphere components and by means of adequate energy input.

Diversity is one of the most important factors determining the stability or non-stability of the elements and parts of the biosphere as well as the AELS. It is obvious that increasing diversity is related to the increase of the system stability.

ENSURING ECOLOGICAL STABILITY

AELS research consists mainly of studying the structural, process, and functional linkages and interactions of the biosphere, technosphere, and sociosphere as well as relationships with appropriate elements in the AELS, including regularities which lead to ecological stability. On this basis it is possible to determine the rules of coexistence of particular AELS parts and, in the case of the sociosphere and technosphere, to determine the rules of non-conflicting biosphere uses.

Research and evaluation of the structure and processes in various AELS types and assessments of load impacts (sort, rate, and combination) enable us to determine the limits of possible load, as well as load potential related to AELS ecological stability. In evaluating AELS structure and dynamics, research concentrates on the description of selected process regularities and on the determination or even quantification of stability functions in particular GES types. AELS ecological stability parameters are determined on this basis. The concept of regional ecological stability is based on the assumption that it can be ensured by means of suitable GES combinations.

The complexity and diversity of landscape systems are expressed by the spatial heterogeneity of geoecological sites and by the number of interactions between them. Landscape system complexity is determined not only by the number of its structural elements but also by the number and character of the hierarchical relationships between these elements (Zonneveld 1975). The smaller and more numerous the geoecological sites, the larger the mutual relations that exist between them and the longer their bordering zones. Between particular geoecological sites there are transitional zones or ecotones which should be studied thoroughly. If the effects of a particular geoecological site are negative, it is possible to compensate through a more suitable transitional GES type (Škopek et al. 1987).

Landscape ecological stability expressed on the basis of complex evaluations of the AELS is understood as the ability of the landscape to maintain a state of equilibrium. This ability includes both resistance to load and resilience in reaction to disturbances. Through detailed investigations of material, energy, and socioeconomic relations or flows between geoecological sites, it may be possible to determine load potential within the AELS. The recognition of the linkages and interactions which exist between AELS subsystems (i.e., inside and between particular geoecological sites and their complexes) and which determine the composition of the AELS and its holistic functions are crucial. Great effort has been directed to the search for optimum proportions of GES composition in accordance with landscape ecological and economic potential in landscape management optimization.

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Landscape Ecology in the Agricultural Fringe of Urban Areas

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Ecology—a word symbolizing the unity of society and environment with both positive and negative feedbacks—has become an important concept since the 1960s in dealing with environmental problems. Because the landscape obviously reflects these problems, a new discipline of landscape ecology has emerged to identify and apply concepts to environmental problems. Unfortunately, this discipline almost ignores the city and its ecological aspects.

In practical terms, the city itself is an ecosystem, open in nature with inputs and outputs of energy and materials. In fact, the city and its surrounding countryside should not be viewed as a dichotomy but as a single ecosystem in which both affect the other. In the fringe where city and country meet, agricultural activities are altered and, at the same time, new urban uses are spread out into rural territory. The rural/urban fringe becomes a problem area where impacts of society on the natural environment are especially evident in the landscape. These impacts depend on adjustments by rural residents, new urban dwellers, and public agencies. This paper describes and analyzes some of these impacts.

The rural/urban fringe has changed in definition and extent. According to the U.S. Bureau of the Census, the urban fringe is that portion of the urbanized area lying outside the central city. The rural/urban fringe, on the other hand, lies beyond the urbanized area and even beyond the boundaries of the Standard Metropolitan Statistical Area (SMSA), more recently called the Metropolitan

Statistical Area. In terms of actual area, therefore, this fringe has become larger.

Until 1970, metropolitan growth took place at the expense of the countryside. Rural/urban migration led to continuous increases in metropolitan areas although decentralization occurred within them to the suburbs. However, in the early 1970s, manifestations of deconcentration emerged, through a process called counter-urbanization. In a population phenomenon without precedent in our demographic history, non-metropolitan counties (i.e., those counties outside the limits of SMSAs) gained net migrants more rapidly than metropolitan areas. Of the 2,471 non-metropolitan counties in the United States—counties not containing a major city or located near one—about 1,450 were growing at a faster rate than metropolitan areas during the period between 1970 and 1975. Counties not adjacent to metropolitan areas were growing almost as fast as adjacent ones. Today, more people are moving into rural areas than are leaving them.

Thus, Americans moved farther out into the countryside to live, to start new industries and develop resources, and to engage in recreation. This region has two components. The daily urban system, including 95 percent of the U.S. population, represents territory whose outer limits include at least five percent of commuters to the metropolitan area. Beyond this is the inter-urban periphery. Both areas make up the urban fringe which is the focus of this paper.

The primary ecological problems associated with the expansion of the urban fringe are impacts of urbanization on rural land including agriculture. Before examining this pressure, however, it is necessary to look at the economic characteristics of fringe land in an ecological context.

THEORY OF LAND USE ON THE URBAN FRINGE

Sinclair (1967) provides a conceptual model for explaining and predicting land uses in the urban fringe. This model is based on the theory of agricultural land use as laid out by Van Thünen in the nineteenth century for an *Isolated State.* In his theory, the more intensive land uses (e.g., market gardens and dairying) are situated on high-rent land near the city in order to reduce transportation costs of moving bulky perishable products to the markets. Farther out, the uses are less intensive and include grain production and livestock grazing. However, when the Van Thünen model is applied to an expanding city, the pattern of agricultural use is actually reversed. Farmers hesitate to invest capital and labor in land near the city because urban uses will outbid agricultural ones. Thus, the sequence of agricultural use becomes less intensive near the city and more intensive farther away.

Bid/rent curves rise with distance from the city as the influence of the city decreases. At the edges of the built-up area, land is either changing to urban uses, is being subdivided, or is being held by speculators or developers for early development. Even farmers who might want to hold out are generally forced from farming by high land prices or taxes, zoning practices, or the nuisances associated with urban living. Organized agriculture is lacking. Where land is destined for urbanization, agricultural land use is of low intensity, often idle, leased for grazing, or rented to urban groups for recreational purposes. Farther out, agricultural intensity rises as the possibility of urban use decreases. In ecological terms, there has been a transition zone of conflicting land uses where conditions are far from optimal for either urban or agricultural use. Urban uses reflect an inadequate infrastructure, especially in terms of water and sewage facilities. Agricultural land suffers from such problems as erosion, over grazing, and groundwater pollution.

Obviously, the land use pattern portrayed in this model is abstract, for in the real world patterns will show uneven growth, leapfrogging over vacant land, and the encroachment of cities on one another. Additionally, public policies such as zoning and green belt laws may act to preserve agricultural land use in the traditional Van Thünen pattern.

IMPACTS OF URBANIZATION ON AGRICULTURAL LAND ON THE FRINGE

The most apparent effect of urbanization on the fringe is the loss of agricultural land to urban development. Recent studies by the U.S. Soil Conservation Service—a 1977 National Resources Inventory and a 1981 National Agricultural Lands Study—found an annual loss of 1.2 million hectares of agricultural land to urbanization. The agency estimated that urban areas of the United States increased by 47.5 percent in the period 1967-1975 and that 28.4 percent of prime agricultural land lay within a 50-mile radius of the 100 largest urbanized areas. All regions of the country lost agricultural land, but the North Central region had the most cropland devoted to non-agricultural uses. Most critical for the future is the warning in the 1981 National Agricultural Lands Study that 44.5 percent of prime or high potential cropland will be subject to urban pressure by the year 2000. However, the 1975 Potential Cropland Study shows that urbanization pressure will be the greatest in areas where high-quality potential land is lowest, e.g., the northwestern and western states.

Sinclair, in support of his hypothesis of less intensive land use in the urban fringe, cites a number of examples which are apparent in the landscape. In studies of Megalopolis—the long strip of coalescing cities with 35 million people between Washington, D.C., and Boston—a high proportion of unused, forested land has been found to result from farm land being abandoned at a faster rate than it was being assumed for urban utilization. Numerous part-time farms have been operated unintensively by wealthy owners whose main income has been derived from the city. In a more recent study of the fringe around metropolitan areas of the Middle Atlantic region, Berry (1978) notes a decline in the number of milk cows. According to Sinclair, agricultural activities involving long-term investment are more directly affected by the anticipation of urbanization than those involving short-term investment. Furthermore, short-term activities place greater ecological pressure on the land.

A somewhat different example is provided by the Montfort feedlots, which in the 1940s represented a modest operation about three miles north of Greeley, Colorado. As Montfort grew to be the largest cattle-feeding operation in the world (150,000 head annually), pressure on the environment became unbearable. The most noticable result was odor pollution. Eventually the entire feedlot facility was forced to move 12 miles to the east. In this case, the impact on agricultural land led to a protest against technology.

Center-pivot irrigation represents a new technological innovation in agriculture that has had severe ecological impacts on the environment. No longer is irrigation confined to flat terrain: rolling ranchland can now be irrigated and cultivated. Center-pivot irrigation not only lowers the water table but also encourages plowing soils—often for the first time—which, if abandoned, may blow and cause severe erosion. The state of Nebraska has the largest number of center-pivots in the United States, and the highest concentration is around the margins of the Sand Hills. Although the impact comes generally from local farmer use, some is from urban areas. In 1976 in one six-county area of the Sand Hills, over one-fourth of the center pivots were owned by non-farmers, absentee individuals, and corporations.

A more apparent example of the ecological impact of urban proximity on agricultural land is the suitcase farmer, an absentee owner who lives and works in the city but farms on weekends, often putting in a crop of wheat with the help of local farmers. Such a procedure creates a problem in the fragile environment of the Great Plains. The primary ecological problem is the plowing of semi-arid grazing land in attempts to make profits; once plowed, the topsoil blows away. In 1936, the county newspaper of Baca, Colorado—located in the heart of the Dust Bowl—acknowledged that 75 percent of the cultivated land was blowing. In the 1960s, however, Baca County was again planted in crops, and the fears of creating a desert-like condition proved premature. Nevertheless, suitcase farmers still exist and have an adverse impact on the land by plowing and planting land that does not represent their main source of livelihood, thus creating a situation that is likely to be harmful ecologically. The Great Plains region is an environment of risk agriculture because of low and irregular precipitation, and evidence shows that risk agriculture is less stable when operated on an absentee basis.

IMPACTS OF URBAN LAND USES ON RURAL LAND

The most apparent effects of urbanization on the landscape and ecology of fringe areas are related to the impacts of actual urban uses. These impacts are both direct through the movement of people into the fringe or indirect as seen in uses that are aimed at supporting urban residents in the city. In both cases, urban and rural interests clash and make the solution of fringe problems difficult.

The provision of better highways after World War II—especially the national interstate system which was built through many major American metropolitan areas—allowed increasing numbers of urban residents to consider the countryside as a place to live. This rural non-farm population increased from 27 million in 1940 to 47 million by 1978. Their settlements are of two types. The first—often called "buckshot development"—includes individual houses on large acreages whose owners want the privacy of a rural location, often for the purpose of gardening or raising horses. Generally these developments are not attached to any existing settlements and depend on wells and septic tanks for water supply and sewage disposal. However, if the density of houses becomes too great from lots that are too small, or if ecological controls do not exist because of locations on county land, the pressure on septic tanks becomes great. In the 1960s, one-half of the wells of a Minneapolis suburb were infected from adjacent septic tanks. Furthermore, even though developments make up only a small percentage of land, all of the land becomes committed to urban development with concomitant speculation and rising land prices.

The second type of urban-oriented settlement is the large subdivision developed in the country to house urban residents seeking to escape the congestion, insecurity, regulations, and high land prices of American cities. Subdivisions are generally located in incorporated or unincorporated suburbs where land use and environmental controls are less strict than in central cities. In some cases, these settlements are retirement communities located on rural land close to forest areas and lakes, representing minor loss of prime agricultural land. More often, however, they are, in effect, dormitory subdivisions on prime agricultural land with neglible commitment to the rural area. By depending on the nearby city for jobs and services, these settlements increase pressure on the environment. Water supply and sewage disposal are often administered by a sanitary improvement district, which in turn depends on the future sale of lots and homes to pay off the bonds used for its construction. Subdivisions are frequently separated from the built-up area of the city proper in what is called "leap-frog development," i.e., leaping over land adjacent to the city which is being held open for high priced speculation purposes. The general term for this process of development, whether in single homes or in subdivisions, is *sprawl*. This condition represents a disorganized type of development that places considerable pressure on the environment and makes comprehensive planning difficult, particularly for the solution of regional problems of pollution and transportation that transcend local political boundaries.

The demand from city residents for recreation provides still another ecological pressure on the urban fringe. In the United States, over 1.3 million square kilometers are devoted to recreation and most of this is under federal control. Pressure is greater on sites close to population centers than on distant ones although even the national parks are exhibiting extreme signs of deterioration. In Yosemite Park, for example, cars are now banned. Locally, the creation of new recreation areas with lakes has generated considerable opposition from farmers because of loss of land, together with problems of traffic, law enforcement, and litter. Weekend recreation homes also add to the pressure on land, especially from the lack of taxing power and proper infrastructure. One in 12 American families owns such a home or lot. Often the lots are purchased for investment and if undeveloped can cause environmental problems.

The face of rural fringe has also been changed by industry. From 1962 to 1978 some 1.8 million manufacturing jobs appeared in non-metropolitan counties as compared to 1.4 million in metropolitan areas. Thus, this part of America with 29 percent of the industry and 31 percent of the population is now about as industrialized as the nation as a whole. New rural industry is diversified in type, regionally specialized, and located near urban centers of counties. Factories secure the benefit of lower costs in terms of land, labor, and taxes while adding to the tax base of the community or county. Chief negative factors are energy costs—chiefly transportation—and an antipathy to this new type of activity in traditionally rural areas. In addition, significant environmental impacts arise in terms of traffic, requirements for infrastructure, and waste disposal.

Land uses connected with mining and power make strong impacts on rural land. Construction materials, including both gravel pits and stone quarries, take urban fringe land away from other uses, especially near cities where proximity reduces the high cost of transporting these bulky materials. The impact of surface coal-mining activities is particularly severe because the pits are extensive and expensive to reclaim. Problems include water supply and waste or slag at the mines as well as services for expanding settlements. In portions of Wyoming, Montana, and North Dakota, large deposits of low-sulphur coal are being exploited as a response to both the national energy crisis and passage of the Clean Air Act of 1970. Environmental impacts in this fragile, semi-arid region will be great because of the concentration of mining: 93 percent of the sub-bituminous, strippable, low-sulphur coal is located in four contiguous counties in northern Wyoming and southeastern Montana. In 1977, 16,000 square kilometers was disturbed by surface mines and only one-sixth of that amount had been reclaimed artificially. Accompanying mining, of course, is the generation of steam power. Farmers object to the loss of land and water to the power plants and to the dangers inherent in high voltage transmission lines. Opposition to the 500,000 volt line proposed by the Nebraska Public Power District to link the state with the Canadian province of Manitoba clearly illustrates this trend.

One of the greatest impacts of urban areas on the fringe land of cities is toxic waste disposal. Although many disposal sites are well designed sanitary landfills, the majority are open dumps. In 1974, the U.S. Environmental Protection Agency (EPA) reported over 17,000 waste dumps in 46 states. Another source estimates that these dumps average 13.6 hectares and occupy a total of 190,000 hectares. Approximately 500 new dumps are added each year. Obviously, such dumps create urban/rural conflicts from loss of land and from air, water, and visual pollution. In addition, the land is forever lost to some types of use unless expensive reclamation is undertaken.

PRESERVATION AND CONTROL OF FRINGE LAND

The magnitude of ecological problems in the urban fringe calls for some degree of control not only to preserve land but also to monitor the impacts of agricultural technology and urbanization on the environment. The problem, of course, is that land use controls in rural areas have always been resented as an invasion of free enterprise and individual property rights. Although some studies show that rural residents are now more aware of the dangers to the environment, acceptance of planning is far from uniform. However, local control is more acceptable than state or federal control. Because of numerous overlapping jurisdictions in the fringe (e.g., incorporated city versus county) some sort of regional jurisdiction is advisable, as pollution knows no boundaries.

Three types of incentives are used to preserve farm land: tax relief, agricultural districts, and right-to-farm legislation. By far the most common is tax relief from paying market values based on potential urban use. Thus, differential assessment in 28 states permits lower agricultural use-value assessment if the farmer agrees to continue farming. If the farmer sells for another use, higher back taxes must be paid. Sometimes such laws are called "Green Belt" legislation. The other types of incentives—districts and right-to-farm legislation—are less common. The latter prohibits local government from enacting laws that unreasonably restrict farming practices unless they are needed to protect the public health or safety. Districts are created to prohibit any non-agricultural activities.

Three types of land use controls are also used to protect agricultural land—agricultural zoning, purchase of development rights by the local government, and transfer of development rights from a preservation area to a development area. By far the most popular of these is the first: non-exclusive zoning of land. In this process, non-farm dwellings are allowed to be built but only under certain conditions. The primary restriction is a minimum density of dwellings, either by large-lot ordinances or by an area-based allocation which permits clustering but still retains low density. Such zoning reduces the demand for lots because their cost discourages land speculation and subdivision development. In the 1970s, some 270 communities in the United States implemented agricultural zoning programs; a sample of these shows the method to be effective in preserving agricultural land. The most important result is that speculation for non-agricultural purposes shifted from agricultural areas to designated development areas.

Supplementing the incentive and land-use control methods of agricultural preservation are integrated programs for metropolitan areas and for states. Outstanding examples of such programs are the metropolitan areas of the Twin Cities in Minnesota and Dade County, Florida, and the states of Oregon, Vermont, and Hawaii. The programs are fairly comprehensive in their degree of control over land and in the unusual amount of public support required.

The preservation and control methods just discussed emphasize agricultural land. However, the preservation of fringe land used for wildlife habitats is equally important. Such land—marginal crop areas, wet areas near streams and lakes, and forest regions—is not classified as agricultural, yet its preservation is important in providing feeding/nesting, hiking, and hunting areas on a seasonal basis. The impact of people from the city on such areas is just as strong as on prime agricultural land, especially impact resulting from construction, hunting, and recreation. Most states, therefore, have habitat programs generated by a hunting stamp tax. Funds from this tax go toward land acquisition, encouragement of private habitat improvement, and management of habitat on public lands.

CONCLUSION

The mobility of Americans is changing the landscape and ecology of extensive areas of rural land. Not only has prime agricultural land been lost to urban settlement and uses, but the use of agricultural land has also become less intensive, causing some ecological problems. A wave of urban settlement is also advancing into the fringe, bringing houses, industries, and facilities for recreation, mining, power, and waste disposal. Procedures for the preservation and control of rural land have been slow to develop, reflecting the American public's resistance to government planning. However, the drastic impact of these changes on the ecology of the fringe has had some results in terms of public attitudes and willingness to plan more comprehensively in the future. The urban fringe will obviously be the focus of much economic growth in the future, but ecological concerns should not be ignored if a quality environment is to emerge.

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Basic Premises in Landscape/Ecological Planning

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Within the framework of comprehensive ecological research, it is necessary to elaborate new theoretical and methodological approaches in individual scientific disciplines as components of interdisciplinary research on the ecological characteristics of the landscape. The present experience—especially in landscape ecological planning—shows that the methods of study of abiotic components are being successfully worked out, whereas the methods of study of biotic components are lagging behind. This is due to the complexity of biotic phenomena and processes which makes research and spatial expression of these phenomena time-consuming.

All planning activity aimed at utilization, protection, and development of an area, the associated environment, and the available natural resources must be based on knowledge of the ecology of the landscape. Until now, efforts have been focused on learning the preconditions for ecologically optimum utilization of an area. Methodological approaches differ with respect to the complexity and heterogeneity of landscapes and optimization of uses. Interactions between man and nature have not yet been clearly defined, and more concentrated efforts are needed in this regard.

BIOTIC COMPONENTS IN LANDSCAPE RESEARCH

There is a need to develop simplified and applied methods of botanical and zoological research which rapidly clarify the structural and spatial distribution of vegetation and animals. At the same time there should be a basis for gradual intensification of knowledge of the properties of vegetation and animals as components of the ecosystem and landscape. These biotic components are the basic parts of a landscape complex, and they are indices of the ecological properties and processes in the landscape.

The significance of resolving the roles of biotic components in a landscape system is reflected in worldwide and particularly European interest in ecological optimization of utilization of nature. Attention is focused on two basic natural formations, vegetation and grasslands; landscape greenery and swamps are considered separately. A special unit for analysis is the cultural vegetation agroecosystem, which integrates the ecological evaluation and utilization of landscape components in the study of the landscape structure and the function of the individual formation units.

In particular, research has focused on the production functions of the above mentioned vegetation formations within the framework of various projects and programs of organizations such as UNESCO, UNEP, and IUCN. More studies are now being directed toward issues of landscape ecological stability, creative aspects of biotic elements and components, carrying capacity, and ecological corridors and barriers in the landscape. However, these studies are not yet well developed.

CREATION OF LANDSCAPE ECOLOGICAL PLANS

Landscape ecological planning is one of the most important aspects of landscape ecological research and is developing due to the increasing problems in the interaction between society and nature. Global changes in the environment, especially in the natural environment, are reflected both in the development of individual national economies and in the development of human civilization and the world economy. Socialist countries are developing their efforts for scientific and technical cooperation under the coordination of the CMEA Council for Protection and Improvement of the Environment. Among the Council's fourteen topics is one entitled "Protection of Ecosystems and Landscapes," which concentrates on ecological problems of landscape. A special theme concerning landscape ecological planning is included within this framework.

The following landscape and ecological problems are of particular interest:

- Rational utilization of natural resources;
- Creation of ecologically optimum landscape structures and collection of ecological data for territorial planning;
- Creation of favorable living conditions for inhabitants of towns and settlements, and harmonization of the urbanization process with ecological conditions;
- Transformation of nature according to the needs of different branches of the national economy with consideration of ecological conditions;
- Preserving the natural genofund of nature and nature conservation.

International research and cooperation are developing in these areas. First is the cooperation organized by the central United Nations institutions, with the focus on UNEP and UNESCO—the Man and Biosphere (MAB) program. The promotion of cultural contacts is involved in the program of IUCN. The International Association for Landscape Ecology (IALE) focuses on the problems of ecological planning. It was established in 1982 at the Sixth International Symposium on the Problems of Ecological Research of Landscape as a result of long-term Czechoslovak activity in this field. Scientists from 29 countries from all continents participated in the preparatory work for the IALE constitution. The efforts of the socialist countries—and particularly of Czechoslovakia—were aimed at application of ecological principles to the solution of problems in relationships between man and landscape.

LANDSCAPE ECOLOGICAL PLANNING (LANDEP)

An analysis of foreign concepts of applied research studies of landscape/ecological interactions underscores that the Czechoslovak concept comprises application methods from different scientific disciplines, from a comprehensive ecological analysis of a landscape through the synthesis and evaluation of the territory up to the proposal for optimum land use. Individual aspects of such a methodology also appear in the foreign concepts, but there is no single comprehensive concept.

In Czechoslovakia during the last two decades the theory and methodologies of landscape ecological planning (LANDEP) developed as a specific form of complex landscape ecological investigations. A degree of application to the requirements of planning has been worked out. The knowledge so far obtained opens possibilities for developing a new branch of basic research as well as for more complete application of ecological viewpoints in the elaboration of documentation for territorial planning (Ružička edit. 1970, 1973a, b, 1976, 1979, 1982, 1985). In the sphere of theoretical research, LANDEP helps plan the optimal utilization of ecological properties of the landscape to create conditions for harmony between man and the landscape. In territorial planning, LANDEP offers a simplified form of ecological evaluation of territory (EET), which becomes a part of the data base, and in this manner, also a part of the planning process.

The LANDEP concept stresses the need for complex evaluation of the landscape as a territory in which activities of man and society develop on the basis of natural phenomena and processes. The essence of LANDEP—which presents a methodological approach to the solution of problems related to ecologically optimal landscape utilization—has been fairly well elaborated (Ružička, Miklós 1979a, 1981, 1982). LANDEP contains two parts, as illustrated in Figure 1:

- *Landscape ecological data* which focus on inventories and assessments of abiotic and biotic components, current landscape configuration, ecological phenomena and processes, and effects and consequences of man's activities on the landscape.
- *Ecological optimization of landscape utilization* which relies on landscape ecological data, particularly ecologically homogeneous spatial units. Types of landscape/ecological complexes and ecological regions are compared with the requirements and needs of the society in the development of the particular territory. Following the evaluation of the degree of appropriateness of the ecological properties expressed in the various landscape/ecological complexes for the particular social activities, a proposal is made on the most suitable location of the social activities in the landscape in accordance with ecological considerations.

LANDEP is a complex system of applied scientific activities. It includes biological, ecological, geographical, agricultural, silvicultural, and other research methods. These methods are united by the combined methodologies of LANDEP, which is directed toward landscape optimization (Ružička, Miklós 1979a, b).

Optimization through LANDEP may result in a proposal for the most suitable locations of planned social activities in the landscape from the standpoint of landscape/ecological features. Because

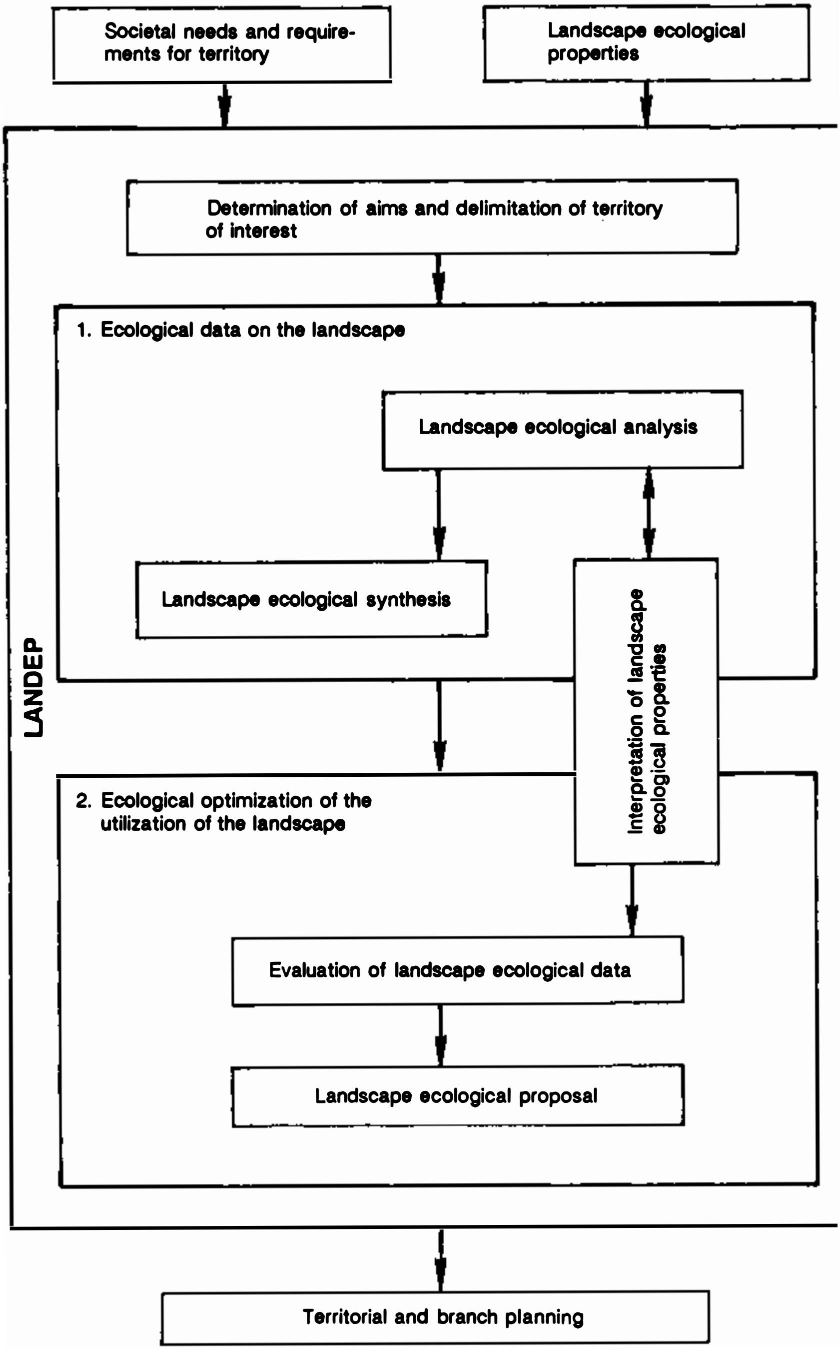

FIGURE 1 The LANDEP concept.

landscape optimization should not in any case retard the economic development of the landscape, the optimization may mean choosing the "lesser evil," i.e., choosing locations where a given activity will be in the least conflict with the natural conditions. This choice can be made by means of the complex process of LANDEP (Ružička, Miklós 1979a).

LANDEP results in the optimal location of social activities in the landscape, taking into account several very important points:

- The choice, extent, and mode of elaboration of data on natural conditions is not left to good intentions, professional knowledge, or common sense of the urbanist. Rather, an integrated proposal of spatial organization is developed from ecological data and contains clear-cut views on the ecological proposal.
- LANDEP does not contradict economic development because it respects all categories of landscape utilization required by society. The role of LANDEP is to facilitate an ecological arrangement of such societal requirements in a given territory.

Although LANDEP is applied to socioeconomic categories of territorial development, natural indices play a crucial role in the localization of these categories. This is motivated by an effort to preserve the "life" of the landscape in harmony between economy and ecology.

LANDEP, as part of landscape ecological research, can be developed only on a team basis. The composition of the team reflects the needs of LANDEP. Each member of the team must possess the skill to obtain the necessary published and unpublished data and to elaborate their topic from the standpoint of its use in the LANDEP program. The amount and quality of data on the landscape employed in LANDEP and EET must be modified according to their significance and their use for theoretical and practical aims.

To verify and modify the LANDEP methodology, approximately 90 projects were designed for different purposes from small to large territories (scales from 1:500 to 1:500,000). Close collaboration with territorial planning activities makes it possible to elaborate simplified methods of LANDEP which could be used by design institutions. To work out these simplified methods, more ecological working teams are being included in design institutes for territorial planning and for planning the development of agricultural production.

FURTHER DEVELOPMENT AND OBJECTIVES OF RESEARCH

For solving the questions of ecological evaluation and utilization of the biotic components of the landscape, simplified and applied research methods on vegetation and animals should be developed. A better understanding of the characteristics of their ecological structure and spatial expression is needed. Biotic phenomena and processes should be investigated as indicators of ecological landscape characteristics.

The principles and methods used in the creation of landscape ecological plans should be focused on harmonization of landscape utilization with ecological conditions, on guiding controversial interests of the society, and on creating prerequisites for rational utilization and conservation of natural resources.

On the basis of the results achieved thus far in the field of comprehensive research of landscape which have been verified in planning and design practice, principles of landscape ecological planning as a system of applied multidisciplinary scientific methods should be more clearly defined. The methodology of a systems approach to the landscape should be elaborated in a creative way and should be developed on the basis of remote sensing, mathematical methods of evaluation of spatial relationships, and application of computing systems. Formalized methods of ecologically optimum utilization of the landscape should also be defined. They could result in proposals for a new landscape structure and in principles for landscape conservation and creation.

It is necessary to work out various models of landscape ecological plans from general plans to detailed solutions for ecologically diverse territories and different uses. On the basis of these model solutions, a framework for ecological landscape planning should be elaborated at the level of basic research. For the purposes of territorial planning, economic and regulatory practices are necessary to define a simplified method of ecological evaluation of the territory as well as methods for practical application of such evaluations.

APPLICATIONS IN SOCIAL PRACTICE

Knowledge of the ecological properties of biotic components of the landscape can be applied in practice through ecological landscape planning. Such direct application is possible when solving the problems of conservation and rational utilization of the soil fund, optimization of agricultural production, landscape protection against erosion, increased ecological stability, and a number of other questions connected with environmental protection.

Landscape ecological planning and the associated systems approach have social importantance. At present, there is great pressure to solve important problems connected with the national economy and with the development of individual territories. The results achieved in this area have stimulated a number of institutions to cooperate in employing the newly developed methodologies.

The widest application possibilities have been found within the framework of regional planning. This is followed by branch planning when seeking ecologically optimum solutions for use of the land by agriculture, by water systems, by industry, by power engineering, for transportation, or for recreation. Ecological aspects of the utilization of nature and natural resources should be an integral part of the governmental policy for the development of society.

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Landscape Ecology: An Interdisciplinary Research Program

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The German geographer Carl Troll coined the term *landscape ecology* almost 50 years ago to describe the character of various abiotic factors and define landscape areas by estimating the vegetation in the African savannah through aerial photographs. In 1959, Troll published a basic study of landscape which presented a new, more adequately defined concept of landscape ecology based on Tansley's view of the ecosystem. Tansley called the space occupied by an ecosystem an *ecotope*, which was to be the basic unit or "cell" of the landscape.

Through the concept of landscape ecology, Troll attempted to integrate geographic and ecological approaches into the research of natural phenomena. Troll wrote that the geographic approach focused on the regional differentiation of the earth and aimed at understanding the mutual relations of natural phenomena. In contrast, the ecological approach focused on functional dependencies on a vertical line, i.e., among elements of various natural phenomena. Its aim is to recognize the mutual relationships between natural phenomena on a small scale in the ecotope.

This concept of research on natural phenomena is not new in principle, and had already appeared in American science in the middle of the last century under the title "landscape physiology" (F. Guyot, 1849). In Europe, it was L. Waibel (1928, 1933) and J. Granö (1929) whose landscape research ran along these lines.

As a promising research trend capable of integrating various scientific disciplines, especially geography and ecology, landscape ecology became an effective scientific tool for addressing the utilization of natural resources. It penetrated international science as well as ecology and social practices shortly thereafter. The issue of terminology, however, was problematic because the German term *Landschaft* is not easily translated into English as "landscape" has a different meaning. In 1970 Troll therefore suggested that the term *geoecology* should be used instead of landscape ecology to integrate the abiotic and biotic components of the research.

Landscape ecology started to develop rapidly at the end of the 1950s when the well-known German geoecological school was established. It placed emphasis on researching the balance of natural processes in the landscape. Important research problems were human interventions into the landscape system and changes in its substance and energetic quantities. Research was pursued to enhance knowledge of the landscape, to reveal the regularities of the behavior and action of its processes, and to make use of this knowledge in landscape planning.

Since its inception, landscape ecology has been oriented toward determining natural areas with definite features, and later toward studying the balance of natural processes. In the course of the 1960s, landscape ecology began to address the problems of the man/environment relationship. This trend evolved for several reasons. First, in Central Europe—where such research had made considerable progress—the landscape and its natural processes were heavily influenced by man. Second, the public demanded that science play a major role in solving the urgent problems and ecological crises in the man/environment relationship. These problems were not limited to issues of air and water pollution by emissions and to degradation of soil by heavy mechanization and chemicalization of agriculture. What also had to be included among these problems were the insufficiently considered technological interventions into natural systems and the problems of spatial organization of the environment in the widest sense, including urbanization and socioeconomic activities. These issues have played a very important role in the development of landscape ecology in Czechoslovakia as well as in other countries of Central Europe.

Mankind's contemporary global problems are major stimuli for the development of landscape ecology on a global scale. The developed, industrialized countries of Europe and North America are suffering from excessive technicalization of the environment due to rapid industrial innovation, while developing countries suffer from heavy destruction of the biosphere through overpopulation and insufficient control of natural resource utilization.

As mentioned previously, the concept of landscape ecology is not a new one. Without having been specifically labeled as such, this line of research has been pursued for a long time in both North America and Australia, including projects on environmental evaluation and problems of potential carrying capacity of the environment. Specific cases demonstrate the interest and willingness of experts worldwide to accept landscape ecology as a tool to identify solutions to environmental problems. The International Geographical Union (IGU) has a specific working group to address problems of landscape ecology called *Landscape Synthesis: Geoecological Foundations of Complex Landscape Management*, which involves research centers in more than 60 countries on all continents. Other committees of the IGU such as the Geoecological Mountain Committee and activities of the International Association of Landscape Ecology (IALE) further demonstrate worldwide interest in this research, and illustrate the interdisciplinary nature of the cooperation, which brings together geoscientific, biological, and agricultural sciences and principles of forest and water management in the treatment of environmental problems.

The success of landscape ecology in research as well as in implementation reflects the need to solve the growing disproportions in the organization of landscape utilization. The formulation of layout plans usually evolves primarily from analyses of individual branches of the national economy, although attempts to apply more complex knowledge of the landscape have already been undertaken. Sectorial plans—for water management, agriculture, urbanization, communication, etc.—are for the most part firmly based on reliable analyses. However, these plans often serve sectorial interests and goals and partially reflect socioeconomic factors. Natural scientific and socioeconomic analyses do not cover the landscape as a whole, and especially not the landscape as a system. This ultimately complicates the implementation of proposed plans. Various sectorial interests conflict, and after implementation the landscape system often responds negatively with heavy impacts on the environment. Sectorial conflicts can be solved on the global level, but usually without adequate regard for landscape patterns and the ability to fulfill economic functions. Basic research is often not utilized sufficiently in advance to adequately predict consequences, or else it is only utilized in specific conflicting situations.

The current state of landscape organization in the environment calls for a new, integrated approach which landscape ecology can provide by utilizing methodological tools to achieve a systems insight into the landscape. Landscape ecology examines the landscape as a dynamic, spatial system of phenomena which are both natural and socioeconomic in character.

Landscape development is governed by various natural and socioeconomic norms. Natural mechanisms—physical, chemical, and biological—relate to the synergistic and chronological facets of the landscape. Most essential in the new approach to landscape research are the dynamics of the relationships between the elements of the landscape. Ranking among the most significant research problems are issues of the stability of the landscape structure and landscape potential and the ability to fulfill functions related to the needs of society.

The function of the landscape as a societal environment has changed over time. It can be said that it has two faces. For a long time, from the emergence of man until the recent past, the landscape appeared to have unlimited potential for man's use and thus provided great security. The interaction between man and the landscape was therefore characterized by negative feedback, which connected man and the landscape in a relatively stable system. Man's feeling of security with regard to the landscape did not encourage upgrading research on the landscape because existing knowledge was considered to be sufficient.

Due to changes that have taken place and continue to take place in the landscape as the result of the scientific-technical revolution, the landscape began to respond and change. Ever more abundant are the critical phenomena occurring in man's relationship to the landscape that seem to point out that the landscape is not an essential, but only accessorial, property that may be forfeited by inappropriate utilization and by overloading its carrying capacity with various human activities and interventions. This "second face" has confronted man with the necessity of quickly and radically modifying his activities in order to preserve the landscape. The interaction between man and landscape has recently been characterized by positive feedback, which connects man with the landscape in a dynamic, accelerating system exhibiting a global and social dimension.

The basic aim of landscape ecology is to contribute to solving the problem of harmonization of three facets of the man/landscape relationship—biological, economic, and social—as well as the problem of rational landscape utilization based on scientific research. It is also undesirable to favor one point of view, either harming the landscape through exploitation of resources without regard for natural conditions or harming society by delaying economic development due to overemphasis on landscape conservation. Landscape utilization must ensure the economic demands of society while preserving the developmental conditions of the biosphere and individual landscape components. Landscape evaluation must therefore be approached from the landscape-user and inhabitant's point of view as well as with consideration of landscape components. The systems properties of the landscape are thus synthesized for potential utilization. Landscape potential embodies both the adequacy of its natural and socioeconomic characteristics for pertinent use and, at the same time, the social interest in preserving the long-term reproductive capacity of the landscape to ensure continued functioning of the landscape and fulfillment of its environmental potential.

The landscape ecology research program may be used to address all basic problems of landscape utilization, in the domain of urban systems, agriculture, water management, tourism, or other branches of the national economy. The composition of the interdisciplinary team depends upon the solutions required for individual problems. Landscape ecology provides for the effective cooperation of a very broad spectrum of experts in the geosciences, biological sciences, and social sciences. At the same time, it creates the preconditions for excellent future opportunities to improve man's relationship to the environment, which is one of the most crucial problems facing mankind today.

Scientific Tools for Environmental Monitoring

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In performing environmental assessments, measurements are made either over highly localized or site-specific areas or over continuous or nearly continuous large geographic regions which might involve a number of discrete sites. The term *remote sensing* as applied to environmental monitoring means simply the acquisition of environmental information without physical contact between the measured feature or parameter and the measurement sensor. There are obviously trade-offs to consider in selecting a measurement and monitoring system—traditional point monitoring techniques or remote sensing—including the quality of information and the cost of obtaining that information.

REMOTE SENSING

Airborne remote sensing measurements are typically employed to provide information over broad regions where the advantages of rapid, wide area, near-simultaneous coverage can be exploited. In addition, these systems typically can provide spatial coverage in time intervals that are consistent with observing the dynamics of pollutant transport, transformation, and depletion. For many applications, particularly in inaccessible locations and in complex terrain, this technology provides the only opportunity to collect certain data sets.

Remote sensing systems can be characterized as either active or passive depending on whether the system incorporates an energy source in performing the environmental interrogation. In active systems, some fraction of the transmitted energy (laser or light source) is scattered from or absorbed by the target; in passive systems, the measurement depends on the passive reflectance or surface emission of energy from the area of interest.

Both active and passive remote sensing methods have application in environmental monitoring with regard to agriculture-related investigations. A few of the hardware systems are briefly described in this paper, with most of the emphasis being placed on their potential applications.

Passive Remote Sensing Systems

Photography, the most widely used remote sensing technique, has been used for over a century and, as a result, enjoys by far the most advanced development in terms of instrumentation, materials, and interpretation. More recently, thermal scanners and multispectral scanners have gained widespread use. While both of these techniques yield synoptic views that may be useful in the extrapolation from point or limited area measurement data, neither technique holds much promise for the identification of specific contaminants.

Nevertheless, photography continues to be the primary remote sensing technique due to several factors: the well-developed techniques, materials, and equipment; the tremendous information content of an individual image; and the ease of interpretation of data. Also, photography often serves to complement *in situ* measurement data.

The multispectral scanner (MSS) class of systems is based on the distribution of radiant energy from the ground surface over a number of discrete energy bands. The energy level in each band is digitized and recorded separately, and various combinations of bands may be used in interpretation. The bands may extend from the ultraviolet, through the visible and near-infrared, and into the thermal infrared region of the electromagnetic spectrum. The techniques are well-developed, both from the standpoint of scanner hardware and interpretative software. The devices have been used extensively on satellite platforms, but they are also flown on aircraft to obtain even greater image resolution.

Landsat 4 was primarily designed for agricultural applications and crop inventories. The satellite's orbital altitude, along with its seven spectral bands, has made it particularly useful for this purpose as well as for a number of other environmental and geologic applications. The band widths sensed and the pixel or picture element size

TABLE 1 Sensor characteristics (Landsat 4 - TM)

Band	Wavelength Sensed (in micrometers)	Pixel Size (in meters)
1	0.45 - 0.52	30
2	0.52 - 0.60	30
3	0.63 - 0.69	30
4	0.76 - 0.90	30
5	1.55 - 1.75	30
6	10.4 - 12.5	120
7	2.08 - 2.35	30

TABLE 2 Sensor characteristics (SPOT)

	Wavelength Sensed (in micrometers)	Pixel Size (in meters)
Multispectral Mode	0.50 - 0.59 0.61 - 0.68 0.79 - 0.89	20
Panchromatic Mode	0.51 - 0.73	10

for Landsat 4 with its thematic mapper (TM) are shown in Table 1. The Landsat 4 - TM system has about 227 million pixels when all seven bands are used. The increase in resolution over the previous MSS systems (79-m pixel size) with this newer system (30-m pixel size) permits many more structural and morphologic features to be mapped.

The French *System Probatoire d'Observation de la Terre (SPOT)* carries two high-resolution visible sensors which can operate either in a multispectral mode or in a high-resolution panchromatic mode. In addition, the field of view can be directed 27° to either side of the ground track. This feature makes it possible to view a critical area on consecutive days and also, by virtue of the difference in view angles, to obtain stereoscopic coverage. The operating characteristics of the SPOT sensors are shown in Table 2.

Active Remote Sensing Systems

Table 3 summarizes the scattering and absorption processes employed in laser systems and indicates the remote measurement

TABLE 3 Summary of applicable processes for remote sensing

Scattering	Rayleigh	Elastic	$f_1 = f_d$	Lidar
	MIE	Elastic	$f_1 = f_d$	Lidar
	Raman	Inelastic	$f_1 \neq f_d$	Lidar
	Fluorescence	Inelastic	$f_1 \neq f_d$	Fluorosensor
Absorption	Absorption due to vibrations, Rotational and/or electronic			IR, Visible and UV Dial

f_1 = laser frequency

f_d = detected frequency

methods which are based on these principles. The design concept and selected practical environmental measurement applications for two of these remote sensing instruments—the lidar and the laser fluorosensor—are discussed below. In addition, Figure 1 shows the absorption features of many pollutant gases over the region of $< 1 - 15$ um (Yates and Taylor 1960). The range-resolved concentrations of several of these gases can also be quantitatively monitored through the use of the differential absorption lidar (DIAL); however, this system will not be discussed further in this paper.

Lidar Devices

Classical lidar devices are used to profile aerosol distributions in the lower atmosphere. Measurements are made by observing the relative backscattering of the intense, extremely short pulse of laser light as it interacts with suspended particles and molecules. Electronic analyzers monitor the elapsed time from firing the laser to the scattering returns and thereby range or measure the distances to the aerosol layers and the relative concentration of aerosol in discrete volumes within those layers.

The airborne lidar in operational use by the U.S. Environmental Protection Agency (EPA) is a two-frequency system consisting of a neodynium-YAG laser transmitter, a 36-cm Newtonian telescope receiver, and an electronics package which provides for real-time processing and displaying of the range-resolved backscatter from aerosols between the aircraft and the ground and the surface-reflected energy, both at transmitted wavelengths. A flow chart of the system

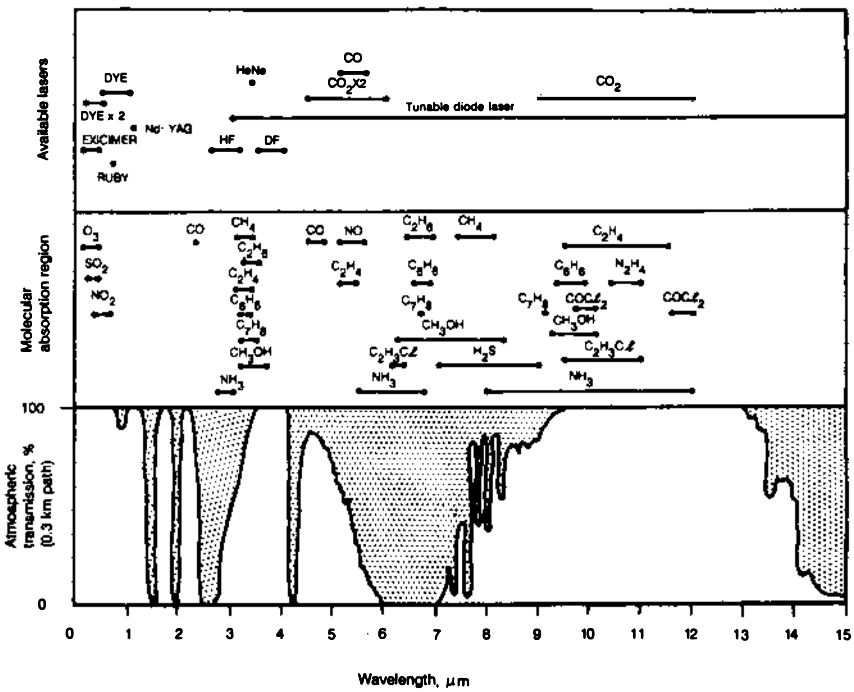

FIGURE 1 Absorption features of various gases.

is shown in Figure 2. The two wavelengths, one in the green (0.53 um) portion of the visible spectrum and the other in the near infrared (1.06 um), are emitted simultaneously with a firing rate that can be varied between one and 10 Hz. At the maximum firing rate and when combined with typical operational air speeds, a horizontal resolution of about 10 m can be obtained. With a laser pulse width of 20 nsec, a maximum vertical resolution of 3 m is likewise obtainable although the signal is usually digitized to yield a resolution of 6 m. Some of the typical applications of lidars are:

- Determining the space and time variability of aerosol inhomogeneities;
- Assessing relative particulate concentrations;
- Measuring the vertical growth of boundary layers;
- Providing input to complex terrain and other atmospheric dispersion modeling efforts;
- Measuring plume opacity;

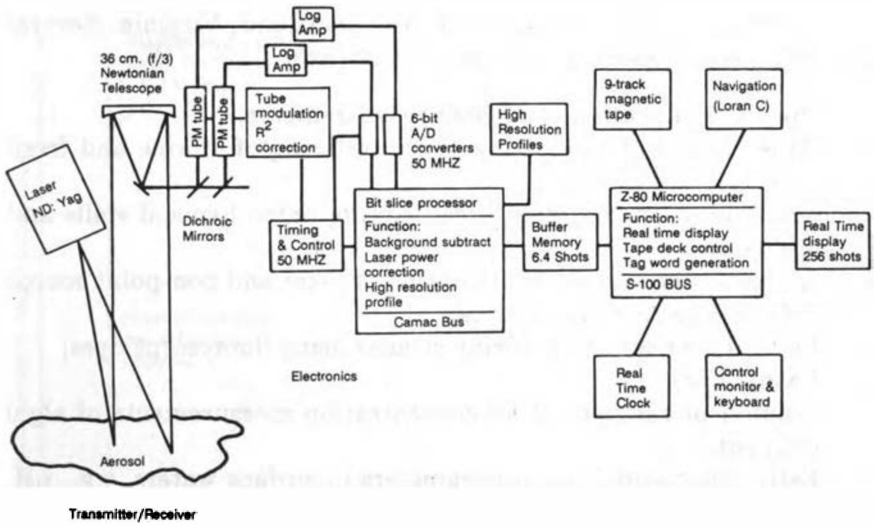

FIGURE 2 Airborne lidar schematic.

- Investigating the mixing of multiple boundary layers using a series of injected fluorescent dye particles;
- Positioning *in situ*-sensor aircraft in an air mass or plume.

One lidar experiment made use of indigenous aerosols to study pollutant transport in the complex coastal environment of southern California (McElroy and Smith 1986). Although the specific application under discussion relates to a coastal environment, several other studies have been conducted well inland to monitor and track the plume created during crop residue burn-offs or from industrial stacks. The procedures employed in the interpretation of the lidar returns are not unlike those described in this experiment.

Laser Fluorosensor

Initially, airborne laser fluorosensing systems were developed to locate and identify the source of petrochemicals in lakes and river systems. Subsequently, developmental efforts were directed at a number of other water quality parameters. Operational airborne systems are in use by a number of research centers including the Environmental Monitoring Systems Laboratory in Las Vegas, Nevada; the Canadian Center for Remote Sensing in Ontario, Canada; the University of Oldenburg, FRG; and the National Aeronautics and Space

Administration (NASA) facility at Wallops Island, Virginia. Several applications for laser fluorosensor systems are:

- Optical attenuation coefficient measurements;
- Observations of the mixing and interfacing of marine and fresh waters;
- Locating, mapping, and fingerprinting petrochemical spills and discharges;
- Assessing the relative contribution of point and non-point source pollution to receiving waters;
- Flow, dispersion, and mixing studies using fluorescent dyes;
- Bathymetry;
- Column or range-resolved concentration measurements of algal pigments;
- Estimating acidification parameters in surface waters, e.g., pH, [Al], [DOC], [HCO_3], [SO_4].

Existing systems are capable of mapping changes in concentrations of chlorophyll *a* and dissolved organic carbon (DOC). The chlorophyll *a* concentration is an indicator of phytoplankton (planktonic algae) activity, and high levels result from high nutrient levels introduced from sewage effluents and agricultural runoff. The concentration of DOC in surface waters indicates the carbon equivalent of the naturally occurring and anthropogenically produced dissolved organic materials present.

A typical fluorescence emission spectrum for the measurement of those two water quality parameters which also permits an estimate of the optical attenuation coefficient for the water column is shown in Figure 3. A broad fluorescence band resulting from the excitation at 475 nm and which peaks at about 540 nm is generally accepted as due to dissolved organic matter (DOM) in the water.

Also observable in the spectrum is the fluorescence band due to the presence of chlorophyll *a* and a Raman emission band from the OH vibrational stretching mode of the water molecules. As that latter peak is a property of only water, and the Raman emission cross section is only weakly dependent on salinity and temperature, it has been demonstrated to be effective as an indicator of changes in optical attenuation, particularly in fresh waters measured at a fixed wavelength (Bristow et al. 1981).

A demonstration of this system, which included correlations of DOC in addition to chlorophyll *a* and the optical attenuation coefficient, was conducted along the Columbia and Snake rivers in

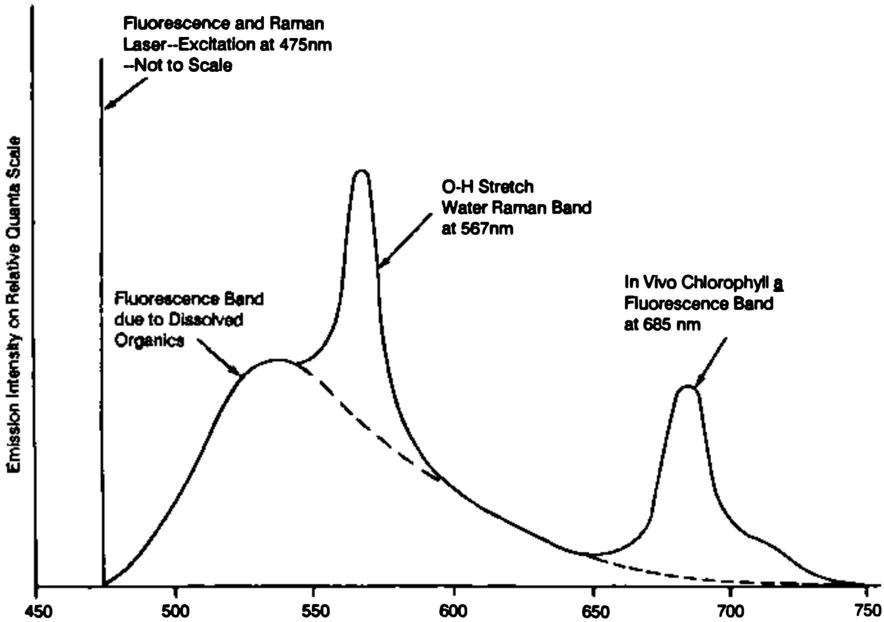

FIGURE 3 Typical fluorescence emission spectrum.

the state of Washington. In addition to the ability of the laser fluorosensor to measure several parameters simultaneously, it was concluded as a result of this study that the interrelationships between the various parameters measured was of greater significance than the measures of the parameters themselves in removing ambiguities and providing insight into otherwise anomalous data (Bristow et al. 1985). The airborne laser fluorosensor data generally exhibited a simple linear relationship with the measured water quality parameters. The system was also able to measure chlorophyll *a* and DOC in highly turbid and generally inaccessible fresh water reaches of the rivers.

GEOGRAPHIC INFORMATION SYSTEMS (GIS)

A primary characteristic of monitoring networks and particularly remote sensing systems is that they produce a vast amount of spatially related data. Effective utilization of these large data sets depends on efficient geographic information systems (GIS) to process and convert the information into a usable form. These systems, which are relatively new, are designed to accept vast amounts of

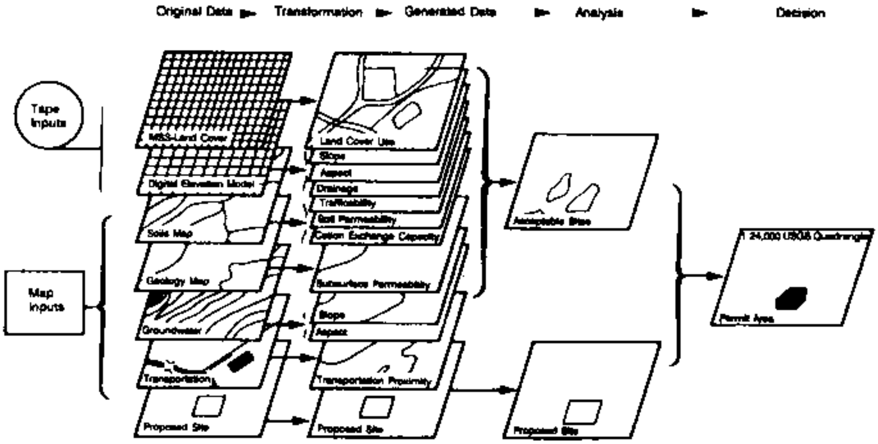

FIGURE 4 GIS concept.

spatial data from a variety of sources, including remotely sensed, and to efficiently store, retrieve, manipulate, analyze, and display these according to user-defined specifications. A schematic of the GIS concept is shown in Figure 4.

All environmental and geologic features can be represented by one of three forms: points, lines, or areas. A feature that at a great distance may be represented by a point may require a polygon to represent its spatial features from a closer perspective. These forms can also be exactly positioned by coordinate systems which provide measurements of such attributes as perimeter length, width, area, and distance and direction between the features.

The GIS must be structured to deal with many non-spatial attributes of these features. The population within a census tract or city or the crop yield from a particular farm are examples of such non-spatial attributes. Both spatial and non-spatial attributes must be digitally represented in the GIS.

A demonstration of the use of a GIS was recently completed for a hazardous waste area in the San Gabriel Basin in southern California (Fenstermaker and Duggan 1986). This 739 square kilometer basin includes 447 wells which provide water for culinary use and for agricultural and industrial purposes. In addition to a number of specific sites, the basin in its entirety is being treated as a hazardous waste site. Elevated levels of trichloroethylene, perchloroethylene, and carbon tetrachloride have been measured in a number of wells within the basin.

Certain feature attributes and relationships between these attributes were examined in order to characterize the groundwater contamination and its impact on the San Gabriel Basin. Specific objectives of this study were to exercise the GIS by describing the cultural and physical surface and underground aquifer features; modeling the groundwater flow patterns and contamination isoconcentration contours over time; displaying the sources of the groundwater contamination through reverse-trajectory analyses; and demonstrating procedures to update the data base.

Included within the GIS data base were other data depicting land use (13 classifications), municipal and census tract boundaries, contamination levels in individual wells, and water purveyor districts. These spatially related data sets were used to depict graphically the population potentially impacted in each of the water purveyor districts which included contaminated wells.

A two-dimensional, Lagrangian flow pathline groundwater model was used to estimate the mean trajectories and transport times for the pollutants to travel from their sources to the well sites. Average potentiometric surface data were used to minimize abrupt changes in direction. Five such data sets were used spanning the period from 1950-1980. The results of this effort for a polygon in the center of the basin which contained 21 contaminated wells provided a series of 10 pathlines from each well to their probable sources of contamination. It was hypothesized that the contamination actually occurred somewhere along or around the endpoints of those pathlines.

The application of this technology to other interest areas such as land and resource management, urban development, marketing, and traffic planning can be readily envisioned. A partial listing of the requirements for such endeavors could include some of the following data types:

Flora and Fauna
Threatened/Endangered Species
Soil Morphology
Moisture Content
Aquifer Extent
Zone of Recharge
Hydraulic Conductivity
Groundwater Quality
- Dissolved Organics
- pH
- Salinity

Critical Habitats
Soil Porosity
Mineral Composition
Texture
Depth to Aquifer
Flow Rate/Direction
Permeability
Meteorology/Climatology
- Precipitation Record
- Temperature
- Wind Speed/Direction

- Total Dissolved Solids

Biological Activity (Soils)
Hydrology
Topography
Slope/Aspect/Elevation
Flood Prone Zones
Depth to Bedrock
Geographic Features

- Temperature Gradient

Soil Chemistry

- Adsorption Coefficients
- Exchange Capacity
- Ion Speciation
- Mineral Content
- Leachability
- Solubility

QUALITY ASSURANCE

Basic analytical methods and instrumentation are fairly well standardized internationally. The discussion which follows, therefore, focuses on analytical quality assurance (QA) and some of the statistical methods utilized to determine the acceptability of data and to assess the relative performance of analytical laboratories. To demonstrate these procedures, a program currently being carried out by the World Health Organization (WHO) and a number of participating countries is presented.

Sweden, Yugoslavia, Brazil, Japan, the People's Republic of China, and the United States plan to conduct human exposure assessment programs at sites in their respective countries. Initially, both exposure levels (e.g., mother's milk, blood, duplicate diets, and inhalation) and environmental levels (e.g., air, water, and soil) of a number of pesticides will be monitored. A pre-qualification phase of the program involves an evaluation of the capabilities of the various laboratories to analyze the study analytes in a number of matrices. A number of performance evaluation materials (PEMs) were therefore developed and distributed to each country. A detailed methodology was also distributed along with such items as gas chromatography column packing materials, analytical standards, and sample preparation chemicals. These materials were provided to insure that the same methods and lots of chemicals were used by the participants, thereby eliminating any possibility of variation due to traceability or uniformity issues. A summary of the results received to date for this qualification phase of the program follows.

Table 4 shows the analytes and their actual concentrations in the various sample matrices. The soybean oil served as a surrogate for human milk, the butterfat served as a fatty food surrogate, and the porcine adipose served as a human adipose tissue surrogate. The standard analytical procedures for pesticides required that each

TABLE 4 Performance Evaluation Materials (PEMs) concentrations (ppb)

Sample Matrix	DDT	DDD	DDE	HCB	-HCH
Soybean Oil	20		20	18.8	
Blood (Low Level)	12.5	9.44	11.24	16.94	8.64
(High Level)	125	94.4	112.4	169.4	86.4
Adipose (Low Level)	59.9	51.9	169.5	39.9	42.7
(High Level)	599	519	1695	399	427
Butterfat (Low Level)	250		990	120	
(High Level)	990		2000	240	500
Water (Low Level)	1.5	1.2	0.82	0.90	1.02
(High Level)	14.97	12.04	8.1	8.97	10.2
Soil (Low Level)	119.8	100.3	105.5	69.8	84.7
(High Level)	1197.6	1003.2	1055.0	698	846.7

sample be divided into three aliquots. A matrix spike (p,p'-DDT) was added to two of the aliquots to provide a measure of any matrix effects. Finally, a surrogate spike (hexabromobenzene) was added to each of the three aliquots as well as to a reagent blank. This spike provided a quantitative measure of the extraction efficiency in each of the samples (i.e., three aliquots plus the reagent blank). The matrix spike would also serve as the surrogate spike if none of the spiking analytes was already present in the sample.

In its *Pesticide Intercomparison Study*, EPA provides an indication of the relative performance of various laboratories (Sovocool and Kantor 1986). The method combines the laboratory's fractional recovery with its ability to qualitatively identify all of the unknown analytes. The fractional recovery is defined as the ratio of the reported value to the reference value if that ratio is not greater than one; otherwise, it is the ratio of the difference between twice the reference value and the reported value to the reference value. An example of this procedure applied to this pesticide PEM program is shown in Table 5 for the butterfat matrix. A 10 percent qualitative scoring was arbitrarily selected for the proper identification of all of the analytes, and 90 percent of the overall score was reserved for the quantitative results.

Prediction intervals are used by EPA to establish analytical acceptance windows in its Waste Water and Water Quality Programs

TABLE 5 Relative performance (low butterfat)

	DDT	DDE	HCB	90% Quant Score	10% Qual Score	100% Overall Score
True Values	250	990	120			
Lab U	115	899	71.8	72	8	80
H	259	1060	50.7	69	10	79
O	223	854	148	76	10	86
E	240	1012	144	78	10	88

such as Drinking Water Laboratory Certification Program, Point and Non-Point Source Discharge Monitoring, and NPDES Permit Dischargers Program (Britton and Lewis 1986). Figure 5 demonstrates an adaptation of that method to the PEM results. After removing obvious outliers, one measurement was randomly selected from each laboratory's report on these *n*-selected measurements, and then the interval end points were calculated by the formula,

$$x \pm (t * s)(1 = 1/n)^{1/2}$$

where x and s are the usual sample mean and standard deviation, and t is the upper 97.5 percentile of the Student's t-distribution with $(n\text{-}1)$ degrees of freedom.

A properly designed quality assurance program includes the identification and quantification of all sources of error associated with each step of the environmental monitoring task so that the resulting data will be of known quality. The components of error, or variance, include those associated with sampling, sample preparation, and analysis. In the past, the major emphasis was placed on analytical QA, although it is now recognized that the component of variance associated with sampling in an inhomogeneous medium such as soils may far exceed that associated with the analytical procedures. Guidelines for soils, vegetation, and sediment sampling quality assurance have recently been developed by EPA, and similar guidelines for groundwater are underway.

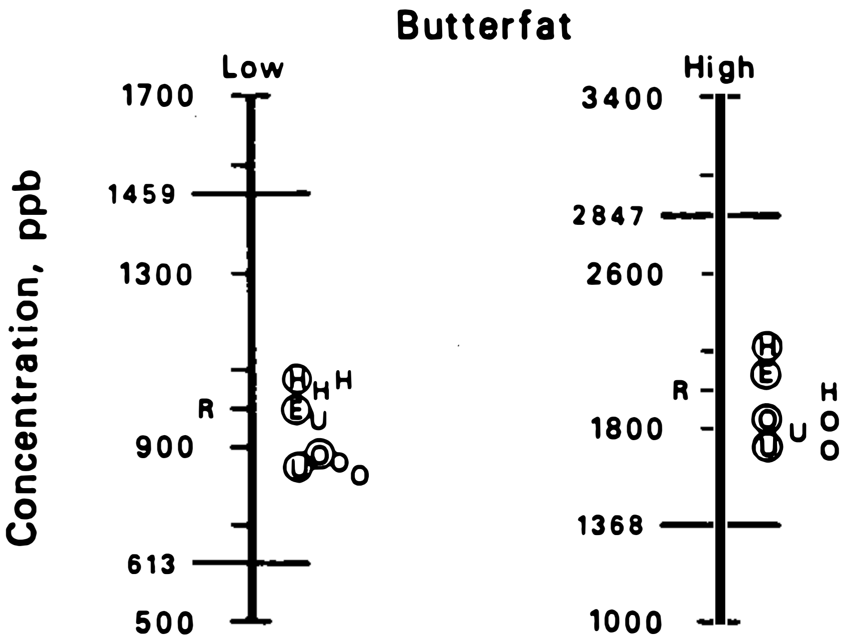

FIGURE 5 Acceptance window for DDE using prediction intervals.

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Scientific Tools for Assessing Environmental Problems in Agricultural Areas

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CURRENT ENVIRONMENTAL PROBLEMS

At present the environment can be defined as a regional system—a unit formed by nature, by activities of individuals, and by activities of society. Its character varies according to the quantity and quality of these three basic components. The environment may be close to natural conditions or alienated from them. It may be characterized by harmonious relations and interactions or by conflicts and antagonisms. It may correspond with man's needs or endanger his very existence.

In any place and at any time, the environment reflects the influence of these three basic environmental components: nature, individuals, and society. We thus focus on these components in all fields of environmental research. This approach is based on the experience that an environment favorable to man originates from the harmony of the functions of the geobiosphere, technosphere, and sociosphere which form the anthropo-ecological environmental system.

Intensive development of any of these three components requires adequate protection and development of the other components if the total anthropo-ecological system is not to lose its environmental value for man. Areas with considerable hypertrophy of one or two of the basic environmental components cannot be considered environments for progressive activities, although they can be special compositional parts of higher units which carry out the functions of the anthropo-ecological system. A current environmental problem is the disturbance of the priority given to the geobiosphere, technosphere, and sociosphere in the total anthropo-ecological system of the earth or in those parts which are described as ecologically impacted. In terms of these anthropo-ecological concerns, a landscape ecological approach to the evaluation of geographic areas and of natural segments of interest has been developed.

AGRICULTURAL LANDSCAPE CHARACTERISTICS

Agricultural activities have always been primarily biological activities. However, as a result of the use of production principles, industrial technologies, and modern management methods, agricultural production has recently become more similar to industrial activities. Specialization, chemical use, mechanization, and automation have invaded agriculture. Agricultural/industrial complexes have been established as a part of an integrated system connected through foreign trade policies with complexes in other countries.

This industrialization of agriculture has brought about numerous negative phenomena which are very similar to the environmental impacts of industrial activities. The concentration and specialization of agricultural production, the intensification of technological measures, the increased use of commercial fertilizers and pesticides with decreased use of farmyard manure, and the use of heavy and effective agricultural machinery have resulted in large amounts of concentrated wastes. Concurrently, there has been an increase in smells and noise, waste heat emissions, pollution of surface and subsurface waters, and high energy consumption. Mechanization causes soil and water pollution from crude oil products and air pollution from combustion products. Intensification of all production, processing, and transport technologies increases the extent and consequences of disturbances and breakdowns.

Changes in agricultural activities and management are closely related—both as a cause and consequence—to changes in the qualifications of farmers, the increase in their living standard, the changes in their lifestyle, and the increase and diversification of their needs and demands. These factors result in substantial changes in agricultural landscape environmental parameters.

From the anthropo-ecological view point there is a considerable disproportion in the development of the structures and functions of the technosphere and sociosphere within the total anthropo-ecological system of the agricultural landscape, which is in turn responsible for the decline of the geobiosphere structure. This development means a decrease in the environmental value of the agricultural landscape.

Selection, manipulation of genes, and other methods influencing the very fundamentals of agricultural production mean a high rate of artificiality. Nevertheless, the biotechnological character of this production is maintained.

The decreasing share of natural, unimpacted geobiospheric components in the composition and function of the environment within agricultural landscapes, together with agricultural/industrial technologies, results in undesirable disturbances and ecological crises. These disturbances limit the net effect of agricultural production and lead to high inputs of finances, materials, energy, and work to stabilize the anthropogenic infrastructure of an agricultural area. According to present scientific/technological development strategy, stabilization measures are necessarily implemented through new technological devices which are foreign to nature and thus increase the share of the technosphere structures in the composition and function of the anthropo-ecological system within agricultural areas.

Post-war agriculture accomplished valuable goals. At the same time, it brought about numerous negative phenomena, and the effects are already quite obvious. Their future consequences cannot be fully estimated at present.

TOOLS FOR ASSESSING ENVIRONMENTAL PROBLEMS IN AGRICULTURAL LANDSCAPES

Undesirable phenomena connected with the changed character of agricultural production are readily solved if their impacts are of direct concern to the viability of the agricultural activities. They are addressed by specialized research and control institutions. The effort is concentrated on departmental goals, mainly on the increase of qualitative, quantitative, and economic effectiveness of agriculture and food production. These institutions must solve more and more ecological problems connected with internal conflicts among agricultural activities. At the same time, they are forced to respect even those impacts which disturb the landscape and limit the possibilities of use other than for agriculture. The solution and prevention of these impacts are obviously among the principal national interests. Therefore, protection of the landscape must be directed and managed through standards, legislation, and decisions above the department level.

In Czechoslovakia, the problem of environmental protection in general, including the environment of agricultural areas, is managed under the direction of the State Commission for Scientific, Technological, and Investment Development. Knowledge of the development and function of the environmental components obtained through routine monitoring by specialized institutions and knowledge obtained through basic and applied research under the State Plan for Science and Technology Development form the scientific basis for decisions and management strategies in the sphere of environmental problems.

The tools for the recognition of the quality of the environment, particularly in the agricultural landscape, are chosen on the basis of the complexity of the problem, i.e., the structure and scope of particular interactions of the technosphere, geobiosphere, and sociosphere components and their influences with respect to particular environmental concerns.

With regard to the technosphere, we investigate land-use structure, i.e., the proportion of land-use types and the location of areas with various land-use types. Attention is focused mainly on the uses and on the impact of user technologies on ecology. From this basic information we derive knowledge as to human influences on environmental components. This knowledge is then processed to develop appropriate approaches for the optimization of anthropo-ecological system unit structure and function. Proposals are then sent to appropriate departments and to the State Commission for Scientific, Technological, and Investment Development where they are used for decisions which determine the intensity of resource use.

Since the environment has a complex character, research must be based largely on models. This requires broad use of various indicators of synergistic environmental factors. It is possible to indicate, for example, the influence of environmental quality on plants and animals, on biological populations and communities, and on ecosystems of various localities. When compared with historical series of measurements and observations, the data obtained enable us to derive the development trends of the environment.

Within the complex of environmental abiotic components, we investigate and use as indicators the qualitative and quantitative characteristics of water and the water regime in soil, especially in differently used areas and in watersheds. The air and soil are similarly investigated, mainly with regard to the synergism of the changes caused by natural or anthropogenic influences.

Indicators of changes in environmental value are not limited to the biological characteristics of plants and animals and the characteristics of water, soil, and air. They also include related indicators of the effects on man and the sociosphere. These indicators are selected from the characteristics of health conditions and from demographic, social, economic, and other characteristics of the population.

The technosphere is the third sphere where the complex characteristics of the synergistic effects of agriculture are considered. We pursue the complex expression of the synergism of the impacts brought about by agriculture on other activities which share resource use in a landscape. As indicators we utilize, for example, losses related to the landscape potential, damage and reparations assessments, and induced production losses.

The indicator method of estimating the value of the environment is advantageous in that it expresses the complex impact of various influences. The disadvantage is its inability to specify the influences of decisive importance within this complex of phenomena. Therefore, the results of indicator research of environmental values stimulate specific hydrobiological, pedological, ecotoxicological, radioecological, and other research activities. These are conducted in cooperation with specialized institutes of basic and applied research. They are aimed at recognition of the mechanisms of undesirable environmental processes. Thus, it is possible to propose principles for ecological management of both agriculture and technology.

Knowledge obtained by environmental quality indicators and by special research on the mechanisms of various technological impacts on the environment in the agricultural landscape is synthesized and used for anthropo-ecological optimization of regional system structures and functions. The basis of the anthropo-ecological optimization of a regional system consists of the following objectives:

- proposals for changes in the land-use structure;
- proposals for technological changes, or for ecologically compatible technologies;
- proposals concerning the protection of those landscape components which are important from the viewpoint of special concerns such as ecostabilization, genetic fund preservation, moisture regime, sanitation, amelioration, and aesthetics;

- projects on forming regional systems of anthropo-ecological stability of landscape structures and functions aimed at prevention of ecological crises and disturbances.

The goal of environmental research and management consists of maintaining the landscape potential for production and residential use. Current methods applied in environmental research rely heavily on computerized data, automated monitoring, and remote sensing. By using automated image analysis, it is possible to increase considerably the effectiveness of geoecological investigations. This permits simultaneous multifactor analytical use of a dense series of observations and measurements and dynamics research of positive and negative phenomena. These methods are continually being improved in Czechoslovakia and promise greater effectiveness in future geoecological investigations.

Assessment of Groundwater Contamination Problems in Agricultural Areas

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ASSESSMENT NEEDS

Groundwater contamination from human activities is an increasingly important environmental concern worldwide. The sources of contamination are many and have included chemical spills in railway or highway accidents; chemical leaks from underground storage tanks, wastewater treatment ponds, and sewage disposal systems; chemical leachate from land disposal of industrial wastes; and pesticide movement from the soil surface after application. Contaminants include synthetic organic chemicals and inorganic pollutants, particularly nitrates and heavy metals. Contamination impacts range from water quality impairment of irrigation sources to human health risks from drinking water supplies. In some cases, contaminated groundwater can also contaminate surface water, especially under conditions of shallow return flows to streams, artificially drained soil systems, and surface water interception of contaminant plumes.

Agricultural production as a source of groundwater contamination and the associated public health risks are the focus of this paper. The major concern over the last two decades has been elevated nitrate levels in water supply wells. More recently, however, the role of pesticides in groundwater contamination has become the focus of intensive investigation. Pesticides can present many possible human health risks, and each risk is chemical-specific.

The evidence of groundwater contamination from agricultural use of pesticides is unequivocal. In some cases, concern for health risks posed by concentrations measured in groundwater has contributed to the decision to ban specific chemicals such as EDB and DBCP, and to restrict the use of others such as aldicarb. These examples suggest the need for continued monitoring for other specific pesticides and development of control strategies.

The widespread use of pesticides presents a number of difficulties. First, pesticides are used over large areas, at different times during the year, and for a variety of farming needs. These variables are further complicated by the well-known variations in soil properties and climate. Such complicating factors dramatically increase the sampling requirements for complete characterization of the system. Actions to clean up pesticide contamination once discovered are not feasible because of the extent of contamination and the associated costs for removal and treatment. A more prudent approach to minimizing groundwater contamination is to evaluate the potential for contamination before a pesticide is released for general use or before an existing chemical is used for a new purpose.

Recent trends in certain pesticide properties are also a cause for concern. For insecticides, the historical trend in chemical solubilities has shown a dramatic increase, ranging from relatively insoluble organochlorines (< 1.0 mg/l in water) developed in the period 1940-1960 to highly soluble carbamates (> 10,000 mg/l in water) introduced since 1970. Persistence for more recently introduced chemicals has decreased, but mobility appears to have been enhanced.

Percolation to groundwater is the mechanism for transport of dissolved pesticides. Agricultural practices that increase infiltration and hence percolation have the potential for increasing chemical leaching. Most notable among such practices is the use of conservation or reduced tillage. By reducing tillage, soil is apparently more amenable to infiltration. Ironically, the dramatic increase in the use of conservation tillage has in part been promoted by the water quality benefits expected. Rainfall runoff, soil erosion, and hence pollutant loadings from conservation tillage systems to surface waters are decreased, but groundwater contamination may increase.

Assessment capabilities are needed to evaluate groundwater contamination by pesticides. The assessment procedures desired depend upon the approaches available to control the problem. Available control options include:

1. monitoring and water treatment;
2. monitoring and pesticide use restrictions;

3. monitoring, pesticide use restrictions, and best management practices; and
4. pre-release evaluation of potential pesticide groundwater contamination.

Note that monitoring is a key element in three of the four control options. Measurements are an essential part of the fourth option but not necessarily directed toward ambient monitoring of pesticide residues in soils or groundwater systems. The basic elements of each of the above listed options are briefiy summarized.

In the first option, contaminated drinking water supplies can be treated for removal of pesticide residues. An effective monitoring program must be maintained to identify treatment needs and confirm continued treatment effectiveness. Once pesticides are identified, the appropriate removal operations must be employed. For trace-level concentrations that can create chronic health problems, such removal technology is costly, must be closely maintained, and can be unreliable. Large treatment systems for municipal water supplies exist but the more rural, less populated areas often will not have such systems. Widespread use of this approach requires extensive monitoring assessments and subsequent design, construction, operation, and maintenance of treatment technology.

The second option involves restrictions on the further use of pesticides after they are discovered as contaminants in groundwater systems. This is an effective way to control current problems and can help prevent future problems. Restrictions can vary from total bans on specific chemicals to reductions in allowable application rates. Assessment methods are focused on sampling procedures, statistical designs, and appropriate interpretation of observed data. A potentially difficult aspect of this approach is the problem of extrapolation, due to the diffuse, highly variable, and widespread nature of pesticide use as well as specific soil/plant/climate conditions. Extrapolation across such a wide range of variables is difficult at best and most often restricts the set of control options available to simple bans or rate-of-use reductions over large geographical areas. Restrictions based on monitoring can prevent some problems in cases where the pesticide has not yet been widely used, but it is essentially a *post facto* approach that requires evidence of contamination before action is taken.

In addition, if extrapolation is to be accurate and risks effectively managed, scientific understanding of pesticide interactions with the environment is essential. A notable example is the ban placed on aldicarb on potato production on Long Island, New York. Contamination of local water supply wells led to an intensive monitoring program for soils, aquifers, and water supply systems. Based on these results, a total aldicarb ban for the region was enacted to prevent further contamination.

The third option for controlling contamination is a refinement of the second option by adding the use of best management practices (BMPs). BMPs are agronomical, engineering, and pesticide use practices that either singly or in combination can prevent or limit groundwater contamination. BMPs for soil erosion have proven to be effective in preventing soil loss and are known to be beneficial in controlling surface water pollution from agricultural runoff. BMPs for pesticides are not as well developed but include methods such as application timing, slow release formulations, chemical substitution, and integrated pest management.

This approach presents several technical and regulatory difficulties. The cause/effect relationships among the BMPs and groundwater contamination must be clearly understood. More importantly, the efficiency of regulation is low because of the dispersed and technically complex set of procedures required. Monitoring requirements are likely to be higher, and the extrapolation problem is further compounded by the uncertain role of BMPs. Successful implementation of BMPs offers a key advantage, however, in that a wider array of safe pesticide use practices can result. One notable example of BMP implementation is the strategy for aldicarb use on citrus in the state of Florida. The application rate was reduced, the timing of application was restricted to avoid excessive percolation from supplemental irrigation, and a total ban was placed on areas closer than 1,000 feet to the nearest well. The assessment methodology used in developing this strategy was comprehensive and included mathematical modeling. Further use of BMPs is elaborated below.

The observance of groundwater contamination is required for the three control options summarized thus far. A more prudent strategy, however, is the prevention of contamination, or at least the prevention of unacceptably high levels of contamination. Acceptable contamination occurs at a level judged to pose acceptable risks to impacted populations. Pesticide regulation as practiced in the United States offers an opportunity to prevent contamination because each new chemical must be evaluated for its environmental and human health risks before it is released for general use. Increasingly, assessments of potential groundwater contamination are being used to specify use restrictions and management practices designed to prevent future problems.

Assessment methodologies for groundwater contamination are actively being developed by research laboratories and are already partially in use by the U.S. Environmental Protection Agency (EPA). These assessments are predictive and must rely on knowledge of specific chemical properties and chemical interactions with the soil/plant/groundwater system as influenced by hydrological and meteorological cycles. Predictive techniques are of great benefit for all of the control options described above. Extrapolation is essentially a prediction problem, and knowledge of pesticide interaction with a wide range of agronomical and environmental conditions can lead to more informed regulatory programs.

A comprehensive control strategy for reducing risks posed by pesticide contamination of groundwater can include a combination of all the options discussed above. Prevention is preferred where possible. Treatment of contaminated water is costly, may be unreliable, and must be maintained as long as the pesticides are in use. Monitoring is a key element in identifying existing problems and in confirming the effectiveness of control strategies. Assessment methods are essential to implement the desired options. The research approach adopted for their development will now be discussed.

RESEARCH APPROACHES

Assessment methodologies that can predict the behavior of pesticides in the environment is the goal of the research approach adopted by EPA. The major phases of the approach include:

- identification and mathematical description of physical, chemical, biological, and transport processes that transform pesticides within soils and groundwater;
- characterization of the environmental properties that influence pesticide behavior in soil/groundwater systems;
- characterization of pesticide use patterns within the environment;
- development of simulation models for predicting leaching and groundwater transport;
- conduct of field model validation studies;
- demonstration of assessment methodologies.

The assessment procedure addresses both commercial chemicals and new chemicals submitted for evaluation and approval by the regulatory authority.

The transformation and transport of pesticides in soils and groundwater can be viewed as the result of the interaction of the hydrological cycle and biological/chemical processes. Processes receiving the most attention to date include:

- *Hydrolysis*: The reaction of chemicals with water can transform pesticides into by-products that are less harmful than the parent compound. Hydrolysis reactions are commonly catalyzed by hydrogen or hydroxide ions. The reactions can occur in both the sorbed and dissolved phases and are pH dependent.
- *Reduction-oxidation*: Redox reactions for pesticides involve the subtraction or addition of electrons. Many such reactions are microbially mediated. Redox reactions are strongly influenced by the oxidation status of soil/groundwater systems.
- *Biodegradation*: Pesticide transformation through biological degradation is perhaps the most significant process. Rates may be influenced by microbial growth rates and the availability of nutrients. In surface soils, this process may be dominant; groundwater systems may be much less biologically active.
- *Sorption*: Pesticide interaction with soil and aquifer materials can retard movement by partitioning the chemical between dissolved and sorbed states. In some cases, kinetic limitations influence sorption. The magnitude of sorption will often depend on sorbent properties.
- *Plant uptake*: Some pesticides are removed from soil solutions by plant roots. Very soluble, highly mobile chemicals can be removed from soil-water to a significant degree.
- *Advection*: Pesticide movement in bulk water flow is the major mode of transport into and through groundwater systems. Recharge and subsequent advection through surface soil layers are determined by the water balance imposed by local hydrology. Movement within groundwater aquifers may be dominated by regional flow fields responding to gradients including recharge.
- *Dispersion*: Pesticide movement also occurs because of dispersive mixing within the porous media. Molecular diffusion and advective mixing combine to spread contaminant plumes.
- *Volatilization*: Pesticide escape to the atmosphere is important in surface soil layers and may play a dominant role in determining the mass of pesticide available for leaching.

The processes just described are dependent upon both chemical and environmental properties. Chemical properties and specific rate constants can be determined within the laboratory, but the problem remains to characterize the environments into which the pesticide is placed. Soil and aquifer properties influencing transport include porosity, bulk density, hydraulic conductivity, and dispersiveness. For sorption and transformation processes properties such as organic carbon content, microbial population density, pH, redox status, and temperature must be known. Such properties must be measured for site-specific assessments. For assessments over regions or other large areas, soil and subsurface data bases must be analyzed statistically and maps must be generated.

Pesticide use patterns and application technology determine the location and manner in which chemicals become part of the environment. This information is key to identifying potential problems for chemicals already in use and provides a focus for analysis of new chemicals not yet in use. Techniques such as map overlays showing the alignment of high recharge areas, e.g., sandy soils in high rainfall areas, are useful in assessments. Another important factor is the mode and spatial distribution of pesticide applications within the target areas. Surface applied chemicals are subject to removal through volatilization and photo-reactions. Soil-injected chemicals may be more amenable to leaching, depending upon chemical properties.

Predictive needs in assessment require the development of mathematical models that systematically combine the transport and fate processes influencing movement to groundwater. The hydrological cycle must be represented in the form of water balance equations and coupled to mass transport or advection/dispersion equations. Often the equations are highly nonlinear and require numerical solutions.

Models developed from process descriptions can be laboratory-validated, but their performance under field conditions must be demonstrated. Detailed field monitoring studies that enable complete characterization of the soil environment and subsequent measurement of the fate and movement of pesticides are necessary. Comparison of these data with the predicted values produced by models demonstrate the uncertainties inherent in the modeling process and may identify model errors or incomplete understanding of the underlying processes.

Models that have been field-validated can be combined with environmental data bases, and assessments at several geographical scales can be completed for specific chemicals. Specific sites may be of some interest, but most often the concern is the risk of groundwater contamination over large areas. Thus, application to a full range of conditions is desirable. Finally, these demonstrations serve as the means to communicate and transfer research results to those charged with chemical regulation or to those interested in more refined development of environmentally acceptable chemicals.

All phases of these research approaches are currently underway within EPA. The multidisciplinary approach of combining elements of laboratory, field, and mathematical analyses has produced groundwater assessment tools now in use for regulating pesticides.

CURRENTLY USED ASSESSMENT TOOLS

EPA requires that each chemical submitted for registration be tested for its physical and chemical properties and its fate characteristics. Typically, laboratory and small-plot experiments to measure rate constants, sorption properties, and transformation products identified above are required. Guidelines have been issued that summarize the experimental protocols as currently defined by the research process.

In cases where commercial chemicals are known to be a problem, monitoring studies are required to better define the problem. Recently, a nationwide statistical survey was initiated to evaluate more fully the extent of contamination in well water supply systems.

Chemical-specific data are used in models to estimate risks posed by the proposed pesticide use. The Pesticide Root Zone Model (PRZM) is used to predict leaching to groundwater for a wide range of geograpical and climatic conditions. The PRZM computes the daily percolation of rainfall or irrigation that moves below the root zone and the associated quantity of pesticides. Modeled processes include runoff, evapotranspiration, plant uptake, sorption, degradation, advection, and dispersion. Detailed model documentation, user's manuals, and the computer code for implementation on either micro-, mini-, or mainframe computers are available.

A complete assessment methodology that includes the fate of leached chemicals in groundwater is not yet in general use. Such a system is under development, however, and research has shown that the integrated approach is quite feasible.

AN ASSESSMENT EXAMPLE

Aldicarb is used as a systemic pesticide for the control of nematodes and other insects in citrus production. A dominant citrus production area is the state of Florida where the subsurface system is characterized by shallow, porous sands overlying three different aquifer systems. The assessment approach adopted for aldicarb included a monitoring and modeling study. Monitoring was completed to determine the current extent of drinking water contamination of municipal water supplies pumping groundwater. Large systems serving highly populated areas in regions of high aldicarb use were sampled. No widespread contamination was found and the majority of the population was not at risk. Previous monitoring studies had discovered well water contamination in shallow wells in rural areas serving only one or two households. An estimate of the risk to existing, small systems and an evaluation of the best policy to reduce such risks were accomplished through a mathematical modeling study.

Process studies of aldicarb demonstrated the degradation pathways. Laboratory and field-plot studies were conducted to evaluate each rate constant. The environmental properties that influence aldicarb leaching and transport included precipitation, evaporation, soil water content, hydraulic conductivity, soil organic matter, pH, and gradient. Statistical characterization of these properties was combined with citrus production and chemical use data to delineate systems requiring analysis as shown in Figure 1.

The system depicted in Figure 1 combines the surface soil zones where aldicarb is applied and the groundwater aquifer systems important as water supply sources. Each of the areas was modeled by combining the PRZM with a groundwater transport model to predict the risk to individual wells downgradient from treated areas.

Typical results are given in Figure 2. These results were used to compare expected concentrations of aldicarb at different distances from the treated area to a health-based standard shown on the figure as 42 ug/1. Using this information, a regulation was developed that allows aldicarb use only on citrus production located more than 1000 feet from the nearest water supply well.

The aldicarb assessment for Florida citrus production demonstrates how quantitative assessment methods are used to identify, control, and prevent pesticide contamination of groundwater. Monitoring and modeling were combined to assess current and future risks. The process-based behavior of aldicarb was investigated using

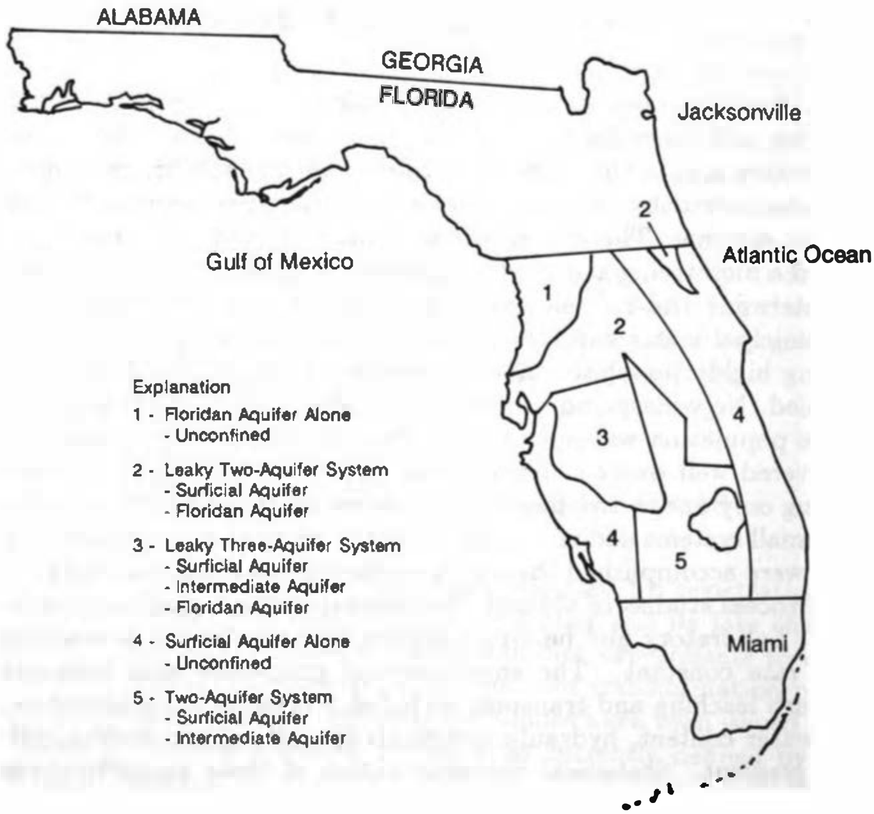

FIGURE 1 **Overlap of idealised unsaturated and saturated areas in Florida.**

laboratory methods developed by researchers. The relevant environmental and chemical use data were developed from soil data bases and census data. Finally, the results were communicated to regulators who developed the control policies designed to permit continued use of aldicarb while preventing unacceptable groundwater contamination.

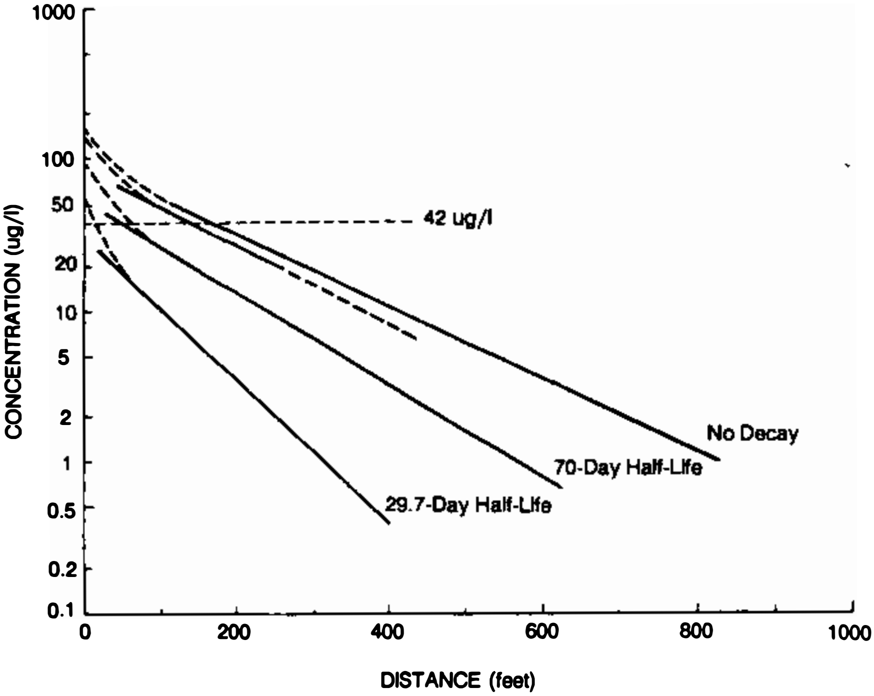

FIGURE 2 Concentration in downgradient well from citrus groves for the worst case year in ten years.

Problems of Water Pollution Related to Agricultural Production

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Large-scale agricultural production accompanied by intensive chemical use is one of the major causes of surface and groundwater contamination. Until recently communal and industrial waste water represented the highest pollution load. At present, agriculture is in the lead in polluting surface and groundwater, and this trend has become a serious problem. Certainly, the concentration of agricultural production into larger units has reduced the number of pollution sources, but the intensity of pollution has risen considerably. The pollution produced by all agricultural resources in Czechoslovakia is equivalent to almost triple the load from population wastes.

In a broader sense, agriculture produces up to 25 types of various pollutants which may be divided, in principle, into five main groups:

- wastes from large, domestic animal-breeding centers;
- wastes from siloing;
- industrial fertilizers;
- chemical plant protection agents;
- pollutants associated with agricultural equipment.

In the first group of pollutants not only are liquid and solid excretions involved, but the pollution produced in maintaining agricultural facilities is also included. A farm with a stock of 400-800 cattle collects up to 400 m^3 of excrement daily. While polluting surface and groundwater in general, these substances are particularly dangerous from the public health standpoint. They contain high numbers of microorganisms, including many pathogenic and potentially pathogenic agents. Their spectrum is relatively wide. They are the causative agents of typhus and other salmonelloses, tuberculosis, anthrax, brucellosis, tularemia, leptospirosis, helminths, and other parasitic diseases.

Wastes and extracts from composts and siloing are inseparably linked to the establishment of large breeding centers. In Czechoslovakia some 25-30 million tons of fodder are siloed yearly. From this amount 10-15 percent leak out into the soil and ground water. The substances contained in these so-called "silo juices" represent a diversified compound of organic matter, particularly proteins. Calculations have shown that these extracts are more than 200 times more concentrated than sewage from the population. At the same time they are a good nutrient substrate for the reproduction of the most diversified heterotrophic bacteria in water.

Especially important from the aspect of either surface or groundwater pollution is the intensive chemical use in agriculture, especially in plant production. More than six million hectares of agricultural land are chemically treated in Czechoslovakia, with a consumption of 60-80 thousand tons of various chemicals. These include both combined industrial fertilizers and substances used for plant protection. In the last 30 years, the volume of nitrogen fertilizers rose in Czechoslovakia more than tenfold. Converted to pure nutrients, the volume of phosphorous and kalium fertilizers grew approximately sevenfold. On average, this currently represents some 270 kg per hectare.

Science and experience have borne out that the use of such quantities of chemicals is irrational since plants are capable of utilizing only a limited part of the nutrients present. The rest enters the surface and groundwater amounting to several thousand tons of chemical substances annually in the republic of Slovakia alone. Detailed analyses of the causes and the character of water pollution have shown that it is the nutrients from the fertilized soil which account for almost 50 percent of the load in the receiving waters. Nitrogen fertilizers have high solubility in water and do not easily become immobilized in soil.

The introduction of large amounts of phosphorus and nitrogen into water results in intensive development of algae and the associated phenomenon of eutrophication, which makes the water useless for many purposes. The costs of treatment rise quickly due to clogged filters and costs in removing odors, tastes, and discoloration. Cases have shown that both domestic and wild animals can die after swallowing polluted water. The mucuous membranes and skin can be damaged, and dysenteric and gastroenteric symptoms have appeared in humans as well.

Worldwide problems have resulted from agents used in agriculture for plant protection, with pesticides ranking at the top of the list. These include preparations involving chlorinated hydrocarbons, organophosphates, bromine, and iodine compounds. Apart from their positive effect on crop production, they exhibit negative properties that are magnified by their incorrect use. The worldwide production of pesticides, represented by approximately 100,000 commercial products, is estimated at 1,500,000 tons yearly. In Czechoslovakia up to 600 preparations are registered, and 182 belong to the group of particularly dangerous poisons. Annual production amounts to about 25,000 tons, representing roughly 3.6 kg per hectare.

From 10 to 40 percent of the pesticides used enter surface and groundwater. These substances may persist in water for long periods, concentrate in sediments or sludge, and accumulate in insects, vegetation, and fish. In estimating the public health hazard of pesticides, it should be noted that under the effect of various ecological factors the original substance may change its original biological properties.

The successful elimination of pesticides from the environment is relatively slow. In water these substances undergo hydrolytic transformations, and these products of hydrolysis are also of concern with regard to public health. Our experiments show that several species of microorganisms effectively destroy pesticides in water, especially those of the genus *Pseudomonas* that utilize pesticides as a source of carbon, nitrogen, and energy. Microorganisms are capable of degrading not only chlorinated hydrocarbons but other types of pesticides as well. Microbial oxidation often occurs. This so-called "co-metabolism" is a significant factor in the removal of noxious biocides from the environment, even if full mineralization to inorganic components is not achieved. As is also known, the concentrations of pesticides usually present in our surface and ground water do not act detrimentally upon the microflora and may be systematically destroyed. Higher doses, however, do affect physiological properties and kill cells. The combination of several substances may have a potentiating effect. These results constitute an additional scientific argument against increasing the quantity of pesticides in the environment.

The application of chemical agents must be regulated in order to achieve the goal of plant protection and elimination of pests without detrimental side effects on man's health and his environment, including food quality. Support should be given to facilitating the transition from contemporary plant protection based on chemical prevention and pest liquidation principles to integrated plant protection involving more natural methods. Such a procedure, which has been successfully developed at the Center for Biological and Ecological Sciences of the Slovak Academy of Sciences, could save millions in local and foreign currency.

Similarly, the pollution produced in connection with up-to-date agricultural equipment is not negligible. This includes the crude oil products of petroleum, fuel oil, and lubricants that enter the soil and then groundwater through careless handling. The amounts involved are quite large. Crude oil hydrocarbons represent a particularly disagreeable type of water pollution; whereas the majority of other wastes form a homogenous system with water, crude oil hydrocarbons produce a heterogeneous environment. Most often they are embodied in emulsions. In larger amounts, the particles subsequently form oil spots or an oil film on the surface of the water, which is often deposited on the shore and covers the macrovegetation.

From the aspect of groundwater pollution the most dangerous pollutants are crude oil hydrocarbons because of their ability to move easily from the source of pollution. Their infiltration into soil is ten times faster than into water. Microorganisms contribute to their elimination in both surface and groundwater. Bacteria from the genera *Achromobacter*, *Bacillus*, *Flavobacterium*, *Micrococcus*, *Mycobacterium*, and especially *Pseudomonas* are capable of oxidizing or degrading both aliphatic and aromatic hydrocarbons. Under favorable ecological conditions, they can degrade in nature at a rate of approximately 7 mg per cm^2 of water surface per day.

We are aware that to satisfy the needs of the population, agriculture should take precedence over many other branches of the economy. What cannot be forgotten, however, is the negative side of this important activity. Measures must be taken to prevent, at all costs, the degradation of the environment, and particularly of such a precious natural resource as water which is becoming a limiting factor in many areas of human activity. Contemporary engineering expertise allows us to take such measures. They only need to be thoroughly and systematically brought to fruition.

Low-Input Sustainable Agriculture Production Systems

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During the last five to ten years terms such as *sustainable* have been used to describe agriculture. Other agricultural terms include *regenerative*, *low-input*, *ecological*, *biological*, *environmentally sound*, *resource-efficient*, and the long-used term *organic*. This last term is generally used to define production systems which either do not use synthetic pesticides and fertilizers or which seek to reduce their use substantially. These terms and practices have come into use because many farmers, scientists, and policymakers have realized that many current agricultural practices are not sustainable due to economic, environmental, biological, chemical, and human problems related to contemporary agricultural systems.

Agriculture as practiced today is a broad continuum ranging from pure organic farming to the use of hydroponics in an almost totally synthetic system. These two views of agriculture represent different philosophies of production. In hydroponics, almost everything is brought through the farm gate, and external inputs are maximized. Sustainable systems tend to minimize the use of external inputs and maximize internal inputs which already exist on the farm. One system tends to dominate or override nature whereas the other tries to use natural processes to the maximum possible extent. Most farmers work somewhere between these two types of production systems.

As chemical inputs have become more numerous during the last 50 years, farmers have moved to use these materials to aid in the production of food and fiber. Now, however, the use of chemicals is increasingly being questioned. Information drawing comparisons between production systems is still relatively scanty; however, such information was almost nonexistent ten years ago. The information comes from whole farm comparisons, replicated experiments, and side-by-side field comparisons. These comparisons and experiments cover broad classes of farms, farming systems, soils and environmental conditions, and experimental and analytical procedures. Many of these are case studies and, therefore, can be viewed as indicative or suggestive but not definitive.

FARM LEVEL COMPARISONS

Conventional agriculture can be characterized by the use of substantial quantities of fertilizers, pesticides, petrochemicals, and other capital inputs in order to maximize production of food and fiber. Conventional agriculture reduces the effective boundaries of a production system to a single crop in a single field in one season. Any production inputs needed to stabilize the system biologically, physically, chemically, and economically are used. For the most part the system is structured by these inputs to conform to the needs of the single crop in order to achieve an optimum yield. Research on such systems tends to be discipline-oriented and deals with individual components.

In contrast, sustainable systems are characterized as agriculture which maximizes the use of internal resources on the farm and consequently minimizes to the extent possible the use of external inputs. In sustainable agriculture the effective system boundary is usually extended to include an entire farm or management unit, its crop or animal enterprise mix, the crop rotation or sequence, and the flow of materials through the system over time. The terms *reductionist* versus *wholistic* have been used to describe the above differences in approach. However, these terms imply value judgments and must therefore be used with caution.

All of the studies comparing conventional and sustainable systems have the weakness of non-random sampling of farms, of varying degrees of precision and completeness in data-gathering, and of the limited number of farms studied. The most extensive data are those from a comparison in the midwestern United States, while the most exact and complete single-farm data are those from east-central Pennsylvania. While such data may have weaknesses, it is important when selecting sustainable farms for study to sample from a very small percentage of total farms, since farms differ in structure, size, farm management capabilities, proximity to market, and physical environment. The studies, for the most part, have addressed such differences very well.

The first significant study in the late 1970s analyzed the corn yields of 26 comparably-paired sustainable and conventional mixed-grain livestock farms in the western corn belt over a wide range of soil types. The mean yield of corn (*Zea mays* L.) from the conventional fields was 8.5 percent higher than from the matched sustainable fields, but this difference was not statistically significant. While conventional corn yields tended to be higher than sustainable corn yields under favorable growing conditions, conventional corn yields were lower when conditions were adverse due to drought. Grain from conventional fields had a significantly higher crude protein content, stalk rot (*Diplodia*), and lodging. Soils from sustainable fields had a significantly higher organic carbon content, higher total nitrogen, but lower Bray 1 phosphorus. Differences in Bray 2 phosphorus, exchangeable potassium, carbon/nitrogen ratio, cation exchange capacity, and pH were not significant. The sustainable farms required about two-fifths as much fossil energy to produce a given value of crop.

This work showed that elimination of conventional fertilizers and pesticides does not automatically result in drastic consequences. It also suggested that considerable reduction in chemical use was realistically possible on mixed-grain livestock farms of the western cornbelt. A further systems comparison in the eastern United States compared conventional with sustainable corn and wheat (*Triticum aesitivum* L.) production and found that sustainable corn and wheat systems were 29-70 percent and 35-47 percent more energy efficient, respectively, than conventional systems.

The long-term sustainability of low-input farms is very apparent in research on complete farms. Results were recently reported from a five-year study (1978-1982) of a 130-hectare crop/livestock farm in eastern Pennsylvania which had primarily used low-input, biological resources since 1973. Crop yields were 10 percent above state and county averages, soil fertility levels were maintained or increased, erosion was reduced, and production costs were 10 percent less than a simulated conventional, high-input farm. Inclusion of forage legumes can be a problem for cash grain farmers because it could reduce their income or result in the production of a crop which is more difficult to dispose of.

The 1980 summary report prepared for the U.S. Congress on sustainable agriculture states the conclusions which have been drawn from all of these studies. These conclusions are:

- Yields per acre are generally equivalent or slightly less than those of conventional agriculture; however, some farms have significantly higher than average yields.
- Few or no insecticides, fungicides, or herbicides are used.
- Production costs are lower by as much as 30 percent, and average about 12 percent lower.
- Energy inputs per unit produce are 50 to 63 percent less.
- A higher proportion of production cost is comprised of labor and machinery cost than on conventional farms.
- Soil erosion is significantly reduced.

These studies are based on data derived exclusively from integrated crop/livestock or field crop farms. None are from vegetable or fruit operations. Also, the data are only suggestive because of limitations of the case study approach. However, taken as a whole, the studies lend sufficient credibility to the six conclusions listed above to warrant continued research on a farm-wide basis with a broad sampling of farms as well as on a controlled, field plot level. The striking results, if confirmed, could have substantial significance for a large proportion of U.S. farms growing similar crops. The environmental implications of reduced disruption from agriculture are also highly significant.

There is growing evidence—although some is very circumstantial—of efficiencies of nutrient flow in sustainably managed systems that are quantitatively different from those in conventional systems. A study of two cash crop farms in the Palouse region of eastern Washington state—one using sustainable methods and the other conventional methods—shows similar results. These side-by-side farms were compared for two years with respect to yield and soil characteristics.

The sustainable farm had not received fertilizer nutrient input since 1909. It used a winter wheat/spring pea (*Pisum satuvum* L.)/Austrian winter pea (*Pisum sativum, pp, arvense* (L) Poir)/green manure or summer fallow rotation. The conventional farm was under a winter wheat/spring pea rotation in which commercial nitrogen and phosphorus fertilizers were used. Soil test data showed increasing levels for organic matter, extractable phosphorus, and potassium for the sustainable farm when compared to the conventional farm. This suggests an upward flow and accumulation of soil nutrients in the upper part of the soil horizon which is similar to natural soil-building processes. The downward movement and leaching of chemicals in the soil under conventional methods has had major implications of groundwater contamination by excess nutrients. The higher levels of extractable phosphorus on the sustainable farm is interesting as it was the conventional farm which received application of the phosphorus fertilizer.

Neither farm received potassium fertilizer; however, the sustainable farm had almost double the amount of extractable potassium as compared to the conventional farm. Both farmers reported yields about equal to or greater than historic yields and local averages. Overall, the measured average yields of both farms were within one to two percent of each other (sum of two crops of wheat and one pea crop) when comparing sustainable and conventional fields. These yield comparisons, however, are difficult to make because they were in different fields on different, but adjacent, farms. Input costs were substantially less on the sustainable farm and the environmental impact was substantially reduced as a result of different inputs. Rill erosion on the conventional sampling sites was greater by a factor of 3.9, which indicates a significant difference in soil loss between the two systems.

Average long-term changes calculated in soil nitrogen and phosphorus pools resulted in substantial deficits of 44 and 14 kg/ha/yr, respectively, on the sustainable farm and 23 and 5 kg/ha/yr on the conventional farm. However, nutrient deficits were not reflected in lower soil nitrogen and phosphorus levels in the plot areas tested on the sustainable farm, indicating that reduced soil erosion and greater efficiency of nutrient cycling more than compensated for the outflow from crop harvest. These results indicate substantially more efficient nutrient use in sustainable systems. Investigators did not know where the nutrients came from in the sustainable system nor where they went in the conventional system, suggesting that there is much to be learned about these production systems, and underscoring the importance of a systems approach in future research.

Contemporary agricultural systems typically rely on chemical inputs to maintain natural balance. To test the necessity of these inputs, Michigan workers during the 1980s studied paired sustainable and conventional farms which grew commercial onions. Control sites were set up which lacked both the chemical sprays of the conventional sites and the biological structuring of the sustainable sites; therefore, outputs fluctuated wildly.

The sustainable sites, while free of chemical inputs, contained a highly structured system of organisms which alone maintained a natural balance. Although the conventional sites were sprayed to decrease pest population levels, this artificial system was not as effective as the natural structure of the sustainable systems. Conventional farmers using repeated sprays of sevin, parathion, diazinon, and malathion experienced higher levels of onion fly for much of the season than did sustainable farmers. It has been reported that sustainable farms experienced fewer pest problems, but this is only preliminary evidence taken from a very pest-susceptible crop.

This is an example of predator/prey and parasite/host relationships. Pesticides used in these systems have also caused secondary pest outbreaks. Much needs to be learned about these relationships, yet even the basic information is not available. Environments have been created which favor the development of resistance and decreased genetic diversity.

REPLICATED RESEARCH COMPARISONS

Research was recently reported comparing crop rotations and manure to agricultural chemicals in dryland grain production in Nebraska. A four-year crop rotation with manure was compared to corn monoculture with fertilizer, herbicides, and insecticides. The rotation also had herbicide and fertilizer treatment and fertilizer-only treatment.

Corn yields for the rotational system were substantially higher than yields for the continuous corn system. Weeds were major deterrents to corn and soybeans on the areas with no herbicides. Tillage with a disc was used for both corn and soybeans which creates conditions that favor weed problems, so it is not surprising to find that there is a problem when herbicides are not used. It may be necessary to change other practices when weed control is changed because soil management and particularly tillage greatly influences what is produced in terms of weed competition.

When corn was under heat and drought stress, yields of corn grown in crop rotation with manure only were comparable to yields of corn grown in rotation with fertilizer plus herbicides, and were better than yields for continuous corn with fertilizer, herbicides, and insecticides. Under good growing conditions corn yields with herbicides, fertilizer, and insecticides were greater than corn yields in the rotation with manure.

In Pennsylvania on a mixed-crop/livestock farm, eleven replicated field studies in 1979 and 1980 on corn following alfalfa showed that supplemental nitrogen as ammonium nitrate or poultry manure did not increase grain yield. This shows that mixed-crop/livestock farms with legumes and manure have excellent potential for internalization of nitrogen production. Other work has shown that insertion of a legume into a row crop such as corn has potential to internalize nitrogen production.

Research on overseeding of legumes into row crops during the growing season or soon after harvest in Delaware, Kentucky, New Jersey, North Carolina, Tennessee, and Maryland has shown that nitrogen in the above-ground biomass was 100 to 225 kg/ha and that yield potential was increased in addition to the nitrogen which was derived from the legumes.

THE TRANSITION

A major problem for farmers wanting to change their production practices from high inputs of chemicals to a system which uses less or none at all has been a lack of specific information on how to make such a change. Research was initiated in 1981 in Pennsylvania to determine procedures which a farmer could follow in making the transition. The research was initiated on land which had been in a cash grain sequence with fertilizer and pesticides for many years.

A cash crop sequence with all contemporary agricultural chemicals was compared to two low-input sustainable systems—a cash grain system relying on legumes and an animal system with legumes and manure. Rotations were started at three points to determine the effect of crop sequence on the transition process. It was found that the conversion process was satisfactory when small grain, legume hay, or soybeans were the initial crops and corn did not enter the rotation until the third year. In a system where nitrogen and weeds were the limiting factors, a soybean/small-grain legume/corn rotation resulted in a satisfactory transition; corn in the first or second year was not satisfactory. Further work in 1986 with a low-input sustainable cash grain rotation showed that relay cropping of barley and soybean was superior to soybeans alone with herbicides. This work also showed that a diverse cash grain rotation utilizing corn, soybeans, small grain, and legume cover crops resulted in excellent internal weed control and nitrogen production. The low-input sustainable system had lower production costs and higher net return than the conventional system, although the corn/soybean conventional rotation also had good nitrogen levels and weed control provided by fertilizers and herbicides.

INSTITUTIONAL CHANGES

Agriculture is an integrated system of knowledge and technologies and should be dealt with accordingly. A more wholistic systems approach to research is needed. Much needed information falls between departmental lines or subject matter areas. Reductionist research creates many undetected problems for the producer as well as the consumer. Reductionist approaches to research in the areas of soil fertility and pest control have led to nutrient runoff and leaching, resistant species of insects and weeds, environmental contamination, and unbalanced production systems with significant soil, health, and economic costs.

Research is also necessary on the following topics:

- As animals have become more crowded, stress and disease are more prevalent; therefore, antibiotics are needed. Recent reports show that antibiotics in animal feeds have led to food animals which are a major source of anti-microbial-resistant salmonella infections in humans.
- New information indicates a relationship exists between fertilizer use and nitrate levels in well water and the incidence of some types of cancer in Nebraska. This shows why systems research from field to consumption is important.
- In the past (1950-1975) yield benefits of rotations were overlooked and almost forgotten as it appeared that fertilizers and biocides could substitute for a rotation. Evidence now shows that in spite of all management inputs a farmer might impose, there is still a yield advantage to be obtained from rotations.
- Tillage now has a major impact on the erosivity of soils. Conservation or reduced tillage is a relatively effective technique, but at present it is a pesticide-intensive system. Use of allelopathic crops, ridge tillage, and other cultural practices could result in crop management which is less dependent on these biocides.

Agriculture is now in a major transition. In the future information will be the driving force regarding farming decisions. This information will make use of biological, chemical, physical, and environmental principles to develop production systems which are more efficient in the use of resources, which provide the producer with a better net return, and which do not create health and environmental problems.

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Protection of Soil Organisms and Improvement of Biological Properties of Soil

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Soil without life is no longer soil. It is a dead substrate which does not meet any of the important functions of soil in ecosystems. This postulate is not quite as obvious as it would seem. There are many famous pedologists in the world who consider the role of biota in soil as a marginal factor. There are even more who treat soil in practice as a substrate able to bear any mechanical or chemical impact. However, the development and the existence of soil are inseparably connected with the development and existence of life on earth.

Soil develops together with the whole ecosystem, and its development has its own laws of succession. Soil organisms have an active role in the development of soils and entire ecosystems. The richness and variability of life in soil can be compared perhaps only with the life richness on coral reefs. Table 1 illustrates the various groups and densities of organisms living in soil. The large diversity, biomass, and number of soil organisms not only concentrate an enormous amount of biogenic elements and energy but also result in properties of soil for which there are no substitutes.

Man's activities have affected directly or indirectly most ecosystems on earth, including soils and their biotic components. The influence has not always been negative. For instance, in meadow soils man has influenced some components of soil organisms in a favorable way while he has suppressed others completely. But the deepest negative impact on soil biota has been in arable soils.

TABLE 1 Density and biomass of soil organisms

Group	Specimens on m^2		Biomass in gm/m^2	
	Average	Optimum	Average	Optimum
Microflora (bacteria, aktinomycetes, fungi, algae)	10^{14}	10^{16}	320	2,350
Microfauna	10^{8}	10^{10}	5	150
Mesofauna				
Rotatoria	10^{4}	10^{6}	0.01	0.3
Nematoda	10^{6}	10^{8}	5	50
Tardigrada	10^{3}	10^{5}	0.01	0.5
Acarina	7×10^{4}	4×10^{5}	0.6	4
Entognatha	5×10^{4}	4×10^{5}	0.5	4
Macrofauna				
Enchytraeidae	3×10^{3}	3×10^{4}	5	50
Gastropoda	50	1,000	1	30
Aranea	50	200	0.2	1
Isopoda	30	200	0.4	1.5
Myriapoda	230	2,800	4.45	13
Insecta	350	16,600	3.5	50
Megafauna				
Lumbricidae	100	500	30	200
Vertebrata	0.01	0.1	0.1	10
		TOTAL	375.17	2,914.3

To understand the role of soil organisms in agroecosystems a basic question must be answered first: What is the role of organisms in soil? Soil organisms can be divided into two groups: soil microflora (bacteria, actinomycetes, micromycetes, and algae) and soil animals (ranging from protozoans to vertebrata). The functions of the groups are different. Soil microflora (except for algae) decompose dead organic matter into simpler chemical compounds and mineral nutrients accessible to higher plants, while soil animals reduce dead organic matter mechanically to smaller pieces and mix them with mineral particles. Zooedaphon takes part in soil microstructure formation—through its excrements, through its active burrowing, and by its transport of particles of organic matter to deeper levels and mineral particles from lower layers toward the surface. Soil microflora are functionally connected with soil animals, and the web of mutual relations among soil organisms is one of the most intricate in terrestrial ecosystems. For example, the functional unity of soil microflora with soil fauna is very important in the humus-forming processes which it accelerates.

There is one other important function of soil organisms which is not sufficiently appreciated. Their large biomass—which averages six tons per hectare—binds all biogenic elements necessary for plant growth. In steppe soil this represents 500 kg of nitrogen, 40 kg of phosphorus, and 45 kg of potassium per hectare. Of course, these nutrients are bound in the living organisms for a longer or shorter part of the year.

Soil organisms differ in the length of their life cycles. Edaphic biota can be divided by size into four groups: micro-, meso-, macro-, and megaorganisms. Microorganisms—including bacteria, actinomycetes, micromycetes, algae, protozoans, and smaller representatives of nematodes—have life cycles ranging from several hours to several days. Mesoorganisms—including animals such as microarthropods, enchytraeids, and nematodes—have life cycles from several weeks to several months. The life cycles of soil macroorganisms last from several months to four years. Finally, the duration of the life cycle of megafauna is several years. In the course of these cycles there is an intensive cycling of soil nutrients. Part of the nutrients is taken by plant roots, and part passes to other cycles of soil organisms. In this light, soil organisms appear to be the most natural fertilizer not only in agriculture, but in all ecosystems. This high diversity of soil organisms and their functions illustrates their important role in soil.

Man affects soil organisms, particularly in agricultural practices.

However, mechanical soil cultivation has a relatively small negative impact in today's modern agriculture, particularly if heavy machinery is not used. Pesticides, inappropriate use of artificial fertilizers, decrease of humus content, and acidification of soils have far greater negative effects on soil organisms.

Pesticides are a major factor influencing soil organisms. The impact of insecticides on soil organisms, especially on different components of soil fauna, is extensive. Recently Edwards (1985) summarized knowledge of this problem. Most studies concentrate on the influence of a defined insecticide on a defined species or group of organisms, and there are only limited data concerning the impact on whole communities of soil organisms and on the effect of chemical processes in soil. A positive as well as a negative effect on one species may evoke a set of changes in mutual relations among different soil organisms in the function of the whole soil subsystem.

The quantity of insecticides applied in agriculture in the temperate zone is substantially lower than the quantity of herbicides. This does not mean that insecticides are not a serious negative pollutant in managed soils in these areas. The CSAV Institute of Soil Biology has a complex research program on herbicide impacts on soil organisms and chemical processes in soil. Some of the results of this research show the complexity of reactions and changes caused by herbicides.

In the field as well as in laboratory experiments with the herbicide *Zeazin 50* (doses 5, 10, 20, and 40 kg/ha), soil organisms were affected to different degrees. Most affected were soil microorganisms and to a lesser extent some groups of soil mesofauna (*Oribatei*). The changes in the composition and dynamics of soil organism communities caused a number of negative reactions in the dynamics of chemical processes in the soil, culminating in such serious changes as the composition and quality of humus and the leaching of phosphorus, nitrogen, and other nutrients from soil.

Toxic and inhibitory properties of herbicides do not disappear by binding with humic acids. Quite the contrary, they remain in the soil as complex compounds, although in this form they are analytically difficult to detect. They have a toxic impact on soil organisms (Rusek and Kunc 1983).

The immunity apparatus of soil fauna is affected after herbicide application and results in increased parasitism in earthworms and other groups of soil invertebrates (Pižl 1985). A long-lasting, intensive application of herbicides in orchards over 5-10 years caused a complete qualitative as well as quantitative destruction of the soil organism community. Only a few species with very low density were left. No soil-forming processes could be identified in those almost dead soils. On the contrary, serious changes in soil microstructure and podzolization processes as well as severe soil degradation were apparent. Similar effects of five more herbicides were shown in forest soil and in laboratory tests. Apparently, these so-called "harmless" herbicides showed strong negative effects on non-target soil organisms and on the soil subsystem as a whole.

The ecological stability of most agrocenoses is very low, with the stability of soil subsystems in most cases higher than the above-ground cenoses. Where soil was heavily affected, the stability of the soil organism cenoses was also low. The loss of ecological connections among species and groups of soil organisms—or even disappearance of a number of them—led to pest infestation, diseases in plants, weeds, and general depletion of the soil. This has been proven by the high densities of plant parasitic nematodes, by a set of diseases in underground and above-ground parts of plants (e.g., *Streptomyces scabiae* and apple scab), and also by the occurrence of different weeds in areas where earthworms were suppressed by insecticides (Edwards 1985, unpublished data).

Experiments at the Institute of Soil Biology are directed to the food preference of soil animals. It appears that different species of soil fauna feed on different species of soil microflora, often on a very narrow species spectrum. For instance, the millipede *Glomeris hexasticha* feeds on the fungus *Botrytis cinerea* which attacks the roots of trees in nurseries. Currently we know little about mutual relations among different species and groups of soil organisms, but in the future it will be possible to make use of the knowledge referring to these relations in biological and integrated plant control. We know already that there are no serious problems with diseases and plant pests in soils where its biota have not been significantly changed.

Over the years we have considered agrotechnics only from the plant-growing point of view. Purposefully, we supported only one component of the agroecosystem—the cultivated plant. The physiology of mineral nutrition of cultivated plants has been elaborated to the finest detail, and chemicalization of plant production has brought about unexpected possibilities to increase yields through fertilization. For many years organic manures were used in Czechoslovakia in very limited quantities. Recently high levels of energy have been supplied to fields in the form of artificial fertilizers. In addition, the greater part of the aboveground biomass is being taken away with the crop.

If we want to preserve all functions of the soil, we cannot continue this exploitation by depriving it of the produced biomass. Consumed energy must somehow be returned to the soil in an appropriate form. Mineral fertilizers serve as nutrition for plants, but for many soil organisms fertilizers are no source of energy at all. Heterotrophic soil organisms need organic substances for nutrition. To ensure a sufficient development of heterotrophic soil organisms, the extracted plant products must be returned to the soil in the form of farm manure or other organic matter. This is the only way to assure a suitable source of nutrients for soil animals which support the soil microstructure.

Just as chemical analysis in soil is indispensable in today's agriculture, biological soil analysis is also necessary. Such analyses are urgent not only for better soil management but also to address the functions of the biological components in soil. We already have methods to assess bioindicators of negative changes in soil. They are operating with changes in whole cenoses, populations, and individual soil organisms.

The factors which negatively affect soil organisms can be placed in five main categories:

- mechanical soil cultivation;
- application of mineral fertilizers in an inappropriate form and at excessively high doses;
- pesticide application;
- monoculture of the same plant over many years;
- incorrect application of irrigation.

However, the risks of negative impacts on soil organisms can be restrained by:

- eliminating heavy machinery in soil cultivation;
- application of mineral fertilizers in combination with organic manures;
- introduction of integrated plant control principles;
- appropriate crop rotation, including plants supporting development of soil organisms such as alfalfa;
- appropriate application of irrigation which does not lead to salinization and compaction of soils.

Of course, there are other factors which negatively affect soil biota—such as soil acidification by acid deposition and buildup of heavy metals—but they are not restricted to agricultural soils and the sources of pollutants are outside agriculture.

Although much has already been accomplished in soil biology, we are only beginning to understand the various processes and interactions in soil. It is clear, however, that the quantity and diversity of soil organisms are directly influencing the function and fertility of every soil type. In recent years there have been many exciting developments in our understanding of how soil physical conditions affect microorganisms (Lynch 1986) and how soil fauna affect nutrient cycling and soil microstructure, but there is still a long way to go. Soil biologists must interact closely with soil scientists, plant physiologists, and farmers to develop a more scientifically-based agriculture.

Many basic questions in soil biology still remain to be answered. Breeding of earthworms or production of microbial preparations have been explored in different countries with varying degrees of success in increasing the fertility of some plants. From the literature we know about successful introduction of earthworms or coprophageous beetles into soils where their absence had caused problems with soil fertility. At present we have no methodology to increase the density and diversity of soil organisms in agricultural soils. We lack methods for complex soil biological analyses which are useable in agriculture as well as methods for drawing conclusions from these analyses. It is necessary to know the functional relations among dominant groups and species of soil organisms and to consider these relations in agrotechnics and in management of biological pests and plant diseases.

Soil biology deals with an enormous quantity of different organisms. Soil microorganisms are sources of streptomicine and other antibiotics, and they produce metabolites with nematicide, herbicide, and insecticide properties. Soil provides a huge source of organisms of industrial significance applicable not only in agriculture but also in other spheres of biotechnology. In soil we must search for compounds applicable as natural pesticides with a minimum of secondary effects on non-target organisms. Soil biologists are thus confronted with the enormous task of transferring results of basic research to practice and assisting in the development of a new industrial branch: the agrobiological industry.

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Resource Depletion and Agricultural Research and Development

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The problems that have occupied agricultural economists in the last 10 years have essentially been solved, given the framework within which these problems were articulated. In 1974, ***The Second Report to the Club of Rome*** carried this warning:

> In ten years food-needy man's back will be even closer to the wall, and in another ten years still closer. Is there really a chance that he will relax his pressure on the ecosystem, or will he continue all over to inflict irreparable damage on nature, which then will retaliate inexorably and mercilessly (1)?

Twelve years later, world agricultural production has in aggregate outpaced population growth. The dominant conceptual framework in the 1980s is quite different, as noted by D. Gale Johnson:

> Intensity of cultivation increased in response to what might be called population pressure. Consequently, at least after a period of adjustment, instead of declining, food production per capita increased as population increased...in a world in which organised research has effectively removed most of the restrictions on production that Ricardo and Malthus attributed to diminishing returns in agriculture (2).

On average, the world's five billion people today are better fed than four billion people were in 1974. Agricultural production has been growing about 0.5 percent faster than world population (3).

The production increase has been almost wholly in cereal yields per acre. This yield increase, in turn, follows agronomic innovations which require increasing intensity of energy use per hectare. Table 1 shows major world increases in tractor use, fertilizer application,

TABLE 1 Annual rates of increase in world agricultural production and inputs, 1975 to 1983

Agricultural production index	2.2%
Cropland, sq. km	0.3%
Cereal yields per ha.	2.5%
Roots and tubers yields per ha.	0.6%
Irrigation, ha.	3.3%
Pesticides, 1983$	4.2%
Tractors, per ha.	2.3%

Source: World Resources Institute (WRI) 1986.

pesticide inputs, and irrigation. The plunge in petroleum product prices since 1985 is certain to have accelerated this trend.

Agricultural production is in aggregate sufficient for present and near-future population levels. The issues are to understand why food sufficiency remains a problem in some areas, how the finiteness of world petroleum resources will affect future agricultural development, and what the implications of long-run sustainability will be for research agendas.

ECONOMIC THEORY OF RENEWABLE AND FINITE AGRICULTURAL SYSTEMS WITH ENVIRONMENTAL EXTERNALITIES

A conventional economic view might frame an optimization problem for maximizing net social value. The value of agricultural consumption is a positive term, the value of resources used as inputs is a cost, and damage to human health and the environment is also a cost. It can be helpful to state this in a formal way to clarify the basic logic and the philosophic problems associated with the economic perspective:

$$max \int_{1987}^{n} \frac{\int_0^Q P_t(Q_t, N_t)dQ - C_t(Y_t, R_t, S_t, L_t, K_t) - D_t(X_t)}{e^{rt}} dt. \quad [1]$$

Let us examine the first term in the numerator, $\int P(Q,N)dQ$. It contains several important assumptions. First, the value of production is measured monetarily. In Figure 1, the area under the demand

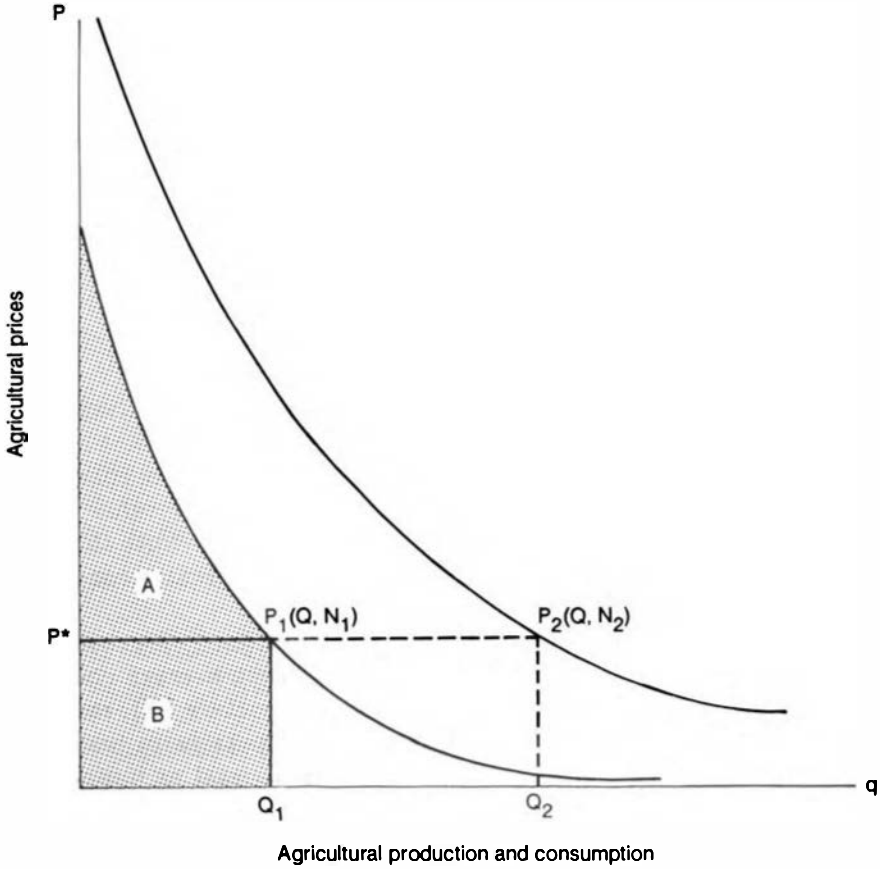

FIGURE 1 The economic measure of consumer value.

curve at Q_1 gives, conceptually, the dollar value of aggregate production. Graphically, the monetary value of agricultural consumption is equal to $A + B$. In economic theory, this monetary measure of value is directly related to the underlying utility that individual consumers and households gain from their consumption. An important corollary of this first assumption is that participation in agricultural markets enhances social value. An agricultural African household that abandons self-production and consumption for market sales and purchases increases the social value of agricultural output.

A second assumption in equation 1 is the irrelevance of equity or distribution of agricultural consumption: a dollar spent on food has the same value whether spent by a Zambian, Czechoslovak, or American. A third assumption has aggregate value increasing directly with population. In Figure 1, for example, the second demand curve P_2 is associated with a higher future population level N_2. Consequently, at the same price P^*, consumption Q_2 and consumer value are both higher with a higher world population N_2. While this paper is not necessarily an endorsement of these three assumptions, they should nonetheless be explicit. Obviously, at some future point population levels and agricultural production and consumption interact.

A useful concept from bioeconomics is the slow approach over time to stable carrying capacity (4). World population eventually decelerates and asymptotically approaches carrying capacity N. It is assumed that this world carrying capacity N is dependent on sustainable yield for agricultural production.

In Figure 1, total cost of agricultural output at population level N_1 could be equal to total revenue $P^* Q_1$. Graphically, total cost is area B. Economists define consumer surplus as the excess of consumer value over cost. This is area A. In summary, consumer value is $A+B$, cost to consumers is B, and consumer surplus is A. Note that the higher population demand curve P_2 would give a greater consumer surplus at the same price P^*.

In the second term in the numerator in equation 1, the cost term is $C(Y,R,S,L,K)$. It is written to emphasize that average cost per unit production (C) is influenced by yield per hectare (Y), research expenditures (R), and the available supply of petroleum resources (S). Of course, labor (L) and capital (K) are at least as important, but the focus here is on resource and environmental dimensions.

Table 1 has shown yield increases for cereals to be sizable at 2.2 percent annually. Many authors attribute this increase to research, education, and extension efforts. In the United States, for example, Braha and Tweeten argue that the domestic productivity growth of 1.8 percent annually is due to growth in farmers' education and public expenditure on research and extension in agricultural production (5). In an American context, they conclude that the economic rate of return has been about 50 percent. In a development context, Barker and Herdt summarize rice research studies and report a median rate of return of about 60 percent on research expenditures (6). As we shall see in the next section, the data imply that research has attained yield gains by developing responsiveness to energy intensive inputs.

The third term in the numerator, $D(X)$, reflects the damage attributable to the production process. The individual variables in the X vector include pesticide residues affecting agricultural workers and consumers, groundwater problems, and the possibility of climate change. It must be recognized that both fossil fuel combustion and petroleum-based chemicals contribute to the two major types of climate change being studied. One, known as the "greenhouse effect," leads to predictions of global warming while the other, ozone depletion, refers to reduced ozone screening of hazardous solar radiation which in turn increases skin cancer rates.

The denominator of equation 1 also carries an important embodied assumption. The term e^{rt} discounts future periods from the perspective of today's decision-making. If r is an interest rate of 10 percent, for example, it means that a billion dollar damage incurred in 20 years is simply 14 percent as important today. In mathematical terms, the discount factor in the denominator of equation 1 defines the weights by which we, in 1987, reduce the significance of events affecting future generations.

There are many alternative ways to define equation 1 formally, which could accommodate many of the problems just discussed. However, the focus of this paper is energy use and agriculture.

ENERGY INTENSIVE AGRICULTURE AND THIRD WORLD AUTOMOBILES

Development economists generally have not considered resource availability or cost as major factors affecting agricultural development. Neither Hayami and Ruttan, de Janvry, Barker and Herdt, nor Mellor and Gavian consider them a problem (7). However, Table 2 shows the considerable energy intensity embodied in modern agricultural practices in the United States. As estimated by Pimentel, 6.9 billion calories are required per hectare for a yield of 7,000 kg per hectare(8). In U.S. measure, this is 11.2 MBtu energy per acre to produce 112 bushels per acre (9).

Nitrogen fertilizer is the single largest category of energy use. The United States is not unique in fertilizer usage, however, since many countries, including China and Japan, use more fertilizer per hectare. Increasingly, synthetic fertilizers are replacing organic fertilizers in developing countries.

There is an important resource problem in anticipating future growth in energy-intensive technologies. The future price and availability of oil will depend upon growth in Third World use of automobiles and air travel. In the United States, transportation uses more than two-thirds of petroleum consumption. For the Third World,

TABLE 2 Energy use in corn production in the United States per hectare

INPUT FACTOR AND MAJOR ENERGY TYPE	QUANTITY PER HECTARE	Energy Mcal/ha
Petroleum-Intensive:		
Gasoline	26 liters	264
Diesel	77 liters	882
L.P. Gas	80 liters	616
Seeds	18 kg	446
Insecticides	1.4 kg	120
Herbicides	7.0 kg	778
Transportation	200.0 kg	51
Total Petroleum-Intensive Inputs per Hectare:		3,157
Natural Gas-Intensive: nitrogen fertiliser 151 kg		2,220
Coal-Intensive Industrial Inputs		
Machinery	55 kg of machinery	990
Electricity	33 4 kWh	96
Phosphorus	72 kg	216
Potassium	84 kg	134
Lime	426 kg	134
Total Coal-Intensive Industrial Inputs per Hectare:		1,570
TOTAL ENERGY INPUT per HECTARE:		6,947

Note: Yield is 7,000 kg corn grain per hectare, equivalent to 24,500 Meal. The calorie output per calories input in energy is 3.5. Drying does not use conventional energy, but may use 7,000 kg stover. Labor input is 12 hours/ha. Sources are Pimental and Hall (p. 8), and Pimentel, 1980 (pp. 9-14, 23-26, 46-47, 55, 72) (see footnote 8). Since crude oil averages 5.8 MBtu per barrel, 3,157 Mcal/ha is equivalent to 2.2 barrels of oil per hectare, or 0.9 barrel per acre. Pimental (1980, pp. 15-16) argues that these last figures should be increased 23.5% to reflect energy needed to produce crude, refine it, and deliver the products to farm use.

the same fraction probably applies: two-thirds of petroleum is used for automobiles, trucks, and airplanes.

Agricultural production itself uses a modest one percent of the U.S. total annual energy consumption of 75 Q (10). With world consumption at 300 Q, global agricultural energy consumption is probably much smaller than three Q.

However, the supply relationships for energy use in agriculture depend upon non-agricultural consumption of energy. The question is particularly important for petroleum. In 1987, proven world reserves are 700 billion barrels, and world consumption will be 20-25 billion barrels. In addition to proven reserves, recent geological estimates of undiscovered oil are about 450 billion barrels (11). Clearly, at a use level of 20-25 billion barrels annually, conventional oil at 1.2 trillion barrels would last about 50 years.

However, there is a major problem. Per capita oil use in the United States is 24 barrels per year. Most of this is used in transportation. If the current world population of five billion attains the same consumption level, global use will be 120 billion barrels annually. Alternatively, if the global population doubles while per capita use attains one-half the current U.S. level, the same 120 billion barrel annual figure results. The ratio now of remaining resources to annual use would be nine years. The continued availability of oil at current prices for the high U.S. consumption rate seems to require that developing countries abstain from similar consumption or higher population, or both.

The changes in world attitudes about oil availability over the last 15 years are due to fluctuations in market structure rather than changes in estimates of resource availability. In 1982, global oil prices reached $34 per barrel, and concern about exhaustion was high. At that time, remaining resources were about 1.3 trillion barrels. Five years later, 100 billion barrels have been consumed, bringing remaining resources to about 1.2 trillion barrels. However, since the price of oil is currently $15-$20 per barrel, there is no concern about availability.

The rapid short-run fluctuations in market power and monopoly pricing should not be confused with the gradual depletion of conventional oil. Many agricultural energy inputs can use other energy forms besides oil. Table 2, for example, shows that nitrogen fertilizer is usually derived from natural gas as an ammonia feedstock.

The remaining resource picture is comparable for natural gas. Table 3 illustrates that present world consumption levels permit, arithmetically speaking, 121 years of consumption. However, if world use attained the U.S. per capita level, that number would decrease to 22 years.

As conventional oil and natural gas resources are consumed, we approach the point where impending exhaustion impacts on prices. It seems clear that energy intensive high technology agriculture can

TABLE 3 Remaining global oil and gas resources

	Oil	Gas
Quantity Remaining	1,150 billion barrels	7,575 trillion ft^3
Energy content, remaining resources	6,700 Q	7,600 Q
Current annual use	20-25 billion barrels	60-75 trillion ft^3
World use at U.S. rate	122 billion barrels	350 trillion ft^3
Ratio, remaining resources to current use	51 years	121 years
to world use at U.S. rate	9 years	22 years

Note: Quantity remaining is the sum of proven reserves and geologically estimated undiscovered resources. Actual studies use probability distributions; this table is derived from modal values. We have used about one-third of our original endowment of oil. Masters (footnote 11), modified by recent consumption data in Monthly Energy Review and Oil and Gas Journal.

continue to expand for several decades. However, at some point in the next century accelerating energy prices will require a new direction in production technology. Hopefully, agricultural researchers will be aware of this problem *a priori* rather than *post hoc*. Future research will need to focus on high yields with less petroleum and natural gas inputs.

Several objections may be raised to this conclusion. First, can today's alternative energy technologies provide substitutes for conventional oil and gas? The answer is negative. Synthetic gas from coal will cost $16 to $20 per 1,000 cubic feet. Synthetic gasoline from coal is more costly, in the range of more than $2 per gallon in production costs (12).

Second, can biomass energy substitute for oil and gas in agriculture? The general answer is, of course, affirmative. Animal and plant wastes are common forms of nitrogen fertilizer and heat energy. Brazil has shown that sugar can be the fuel basis for automotive transportation. The problem, however, is cost. It appears that making biomass liquid fuel is so costly that it cannot be sustained. In other words, it is technically not feasible to visualize an economy in which tractors and trucks are manufactured with biomass energy and then used on biomass farms with biomass fuel to produce liquid fuels for general non-agricultural use. The most widely used processes today require one gallon of conventional petroleum to produce one gallon of conventional ethanol (13). Brazil's debt problem is in part caused by the massive subsidies necessary to support its sugar-based ethanol program.

Finally, can coal or nuclear power replace oil and natural gas as energy sources for agricultural inputs? The answer is not clear. Increased global coal use may create global environmental problems with respect to climate change, upper atmosphere ozone depletion, lower atmosphere ozone pollution, and acid deposition. Nuclear power in the 1980s is much more costly than conventional electricity sources.

The immediate conclusion, then, is that energy intensive agriculture can continue to expand for some decades. Ultimately, however, agricultural research will need to focus on high yields with less conventional oil and natural gas requirements. If developing countries move towards U.S. levels of oil and gas use, this point will arrive much sooner.

FERTILIZER AND FOOD

Ruttan notes that:

> We are, in the closing years of the twentieth century, completing one of the most remarkable transitions in the history of agriculture. Prior to this century, almost all increases in food production were obtained by bringing new land into production...By the end of this century almost all of the increase in world food production must come from higher yields—from increased output per hectare. (14)

About one-half of the growth in yield per hectare will come from increased application of chemical fertilizers, principally nitrogeneous fertilizers. Depending on a limited resource as a major source of food production is not a new phenomenon and has been a matter of public concern since the late 18th century. As in the past, we must search for technologies based on less limiting resources that can be substituted for fossil fuel-based fertilizers as their supply becomes depleted.

There are, however, two factors which distinguish the current situation from previous experience. First, there is the likelihood that the path of depletion will lead to a sudden sharp drop in oil supplies, with the result that the substitution must occur more rapidly. Second, the nature of the substitution differs from the so-called substitution of chemical fertilizer for land. In the latter case, chemical fertilizers added to the land have become the major source of increased output. However, when fossil fuels become depleted, or possibly before that time, a different form of fertilizer technology will be substituted for existing chemical fertilizer inputs. A massive input substitution will be required simply to maintain the gains achieved through application of chemical fertilizers. Clearly, we cannot wait for the secular rise in oil prices to begin before we start planning for this eventuality. Before considering the implications for research and technology development, let us review both the achievements and problems created by the growing dependency on agricultural chemicals as a source of growth in agricultural production.

The sharp rise in oil prices was accompanied by a sharp rise in fertilizer prices. Adverse weather factors were also instrumental in the rise in grain prices. However, Timmer indicates that a decrease in food supply which reduces fertilizer demand in the short run will have as its long-term effect an increase in food grain prices sufficient to restore the profitability of the original level of fertilizer use (15). In short, with a growing dependency on chemical fertilizer, the price of food is becoming inexorably linked to the price of fertilizer. However, while a change in fertilizer prices will lead to a change in food prices, the reverse is not necessarily true. This is because, as noted earlier, agriculture accounts for only a small fraction of energy consumption.

The future is even more problematic. With oil revenues declining, governments can no longer afford the heavy subsidies on fertilizer. Furthermore, while one kilogram of fertilizer nutrients probably led to a yield increase of 10 kilograms of unmilled rice in 1972, this ratio has fallen to about one to five at present. The genetic yield potential of rice has not increased significantly since the release of the first of the high-yielding varieties in 1966.

A number of Asian countries have experienced success in moving toward self-sufficiency with the result that rice prices have fallen, and even at today's bargain fertilizer prices farmers are feeling a cost/price squeeze. Today, policymakers are concerned about the global surplus of grain. However, there is a very fine balance between surplus and deficit in domestic and world grain markets. Even with an infinite supply of chemical fertilizers, crop yield potentials must continue to increase in order to meet future food demands (16). The eventual depletion of oil reserves raises an even stronger warning flag for the distant future. The danger is that today's surpluses will lead to complacency on the part of policymakers and a reduction in investment in agricultural research.

PLANT PROTECTION AND THE USE OF CHEMICALS

Considerable success has been achieved in developing insect and disease resistant varieties of plants using conventional breeding methods. However, private firms and government agencies have continued to promote the use of chemical control and recommend dosages that are often harmful. The case of Indonesia clearly illustrates the problem.

Farmers in Indonesia paid only 10 to 20 percent of the full economic cost of the most widely used pesticides, and the extremely low price led to widespread and heavy applications (17). These high application rates have caused serious ecological problems, poisoning the breeding grounds for fish and shrimp in the coastal waters. Furthermore, the heavy application of chemicals has promoted the buildup of the brown planthopper by destroying the predators of the planthopper and by encouraging the development of new planthopper biotypes. Overuse of chemicals caused serious damage to the 1986 rice crop.

We in the developed world have become considerably more conscious of the environmental damage caused by misuse of chemicals. Why is such misuse being encouraged in developing countries even when more effective plant protection methods exist? What will be the impact of advances in biotechnology on plant protection?

IMPLICATIONS FOR AGRICULTURAL RESEARCH AND TECHNOLOGY DEVELOPMENT

Two issues must be considered. First, we must develop the technologies which will enable us not only to find a substitute for agricultural chemicals, but also to continue to enhance yield potential and growth in agricultural production. Second, we must insure that as many farmers as possible around the world have access to these technologies.

Recent advances in the biological sciences offer the greatest hope for developing the needed technologies. In the broad generic sense, biotechnology includes such areas as tissue and anther culture, wide crossing and biocontrol, and recombinant DNA.

Advances in biotechnology have been more rapid in the animal than in the plant sciences. This is because biotechnology research is conducted in developed-country laboratories. In the developed countries, emphasis is on human health issues rather than food production, and the spillover into the animal sciences has been very large. For example, the research budget for biotechnology research in the U.S. National Institutes of Health (NIH) was $1.8 billion, approximately 20 times the public sector investment in agriculture-related biotechnology.

Most researchers seem to agree that technologies offering improved plant protection will be among the first biotechnologies released for adoption. The most rapid progress is predicted for the development of herbicide-resistant crops (18). This is because resistance is controlled by a single gene, tissue culture can be used to identify the resistant strains, and there appears to be a large potential profit for private firms. Whether herbicide-resistant crop varieties will prove to be less costly than other weed control methods has yet to be determined, but a large market is anticipated. The technology will probably be ready for adoption in some crops in five years or less.

Crop loss due to insects and diseases can be reduced through cultural, biological, chemical, or resistance breeding methods. Relatively little research is devoted to cultural or biological methods because the private sector cannot easily capture the profits. Chemical methods, the most widely used control, are favored by private industry, although an increased emphasis is being placed on the development of disease and insect resistant varieties. The hope is that such varieties, by reducing the demand for chemicals, will be more profitable and more protective of the environment. However, the cost of resistant varieties developed through biotechnology could be even higher than the costs incurred using chemical control. In some cases, biotechnology innovations could enhance the effectiveness of chemical methods. Thus, whether advances in biotechnology will reduce the demand for chemicals remains to be seen.

Biological nitrogen fixation appears to offer the greatest potential as a substitute for chemical fertilizers in the long-term. Historically, this has been an important source of nitrogen in crop production. Not many decades ago crop rotations involving legumes such as clover and alfalfa were commonplace in temperate zone countries. As fertilizer became cheaper, higher yields and greater profit could be achieved by continuously growing crops such as corn. In the tropics, research continues on organic fertilizers and green manure crops such as azolla, sesbena, and lucena. However, these crops require considerable labor and management and do not fix enough nitrogen to provide a complete substitute for chemical fertilizer.

In the examples of symbiotic nitrogen fixation described above, bacteria in the rhizosphere of the plant convert atmospheric nitrogen to nitrate. Managing rhizobium through improved inoculum could significantly increase the yield of leguminous plants (19).

The hope is that biotechnology research can extend nitrogen fixation to non-leguminous plants. There is much debate among scientists as to how long this process will take and whether it can be achieved without significant reduction in plant yield potential. Some are optimistic and believe that it is reasonable to suggest that a nitrogen self-fertilizing plant will be invented by the early 1990s with possible commercial use by the late 1990s. Other scientists feel that it will take a matter of decades to achieve these goals. Whether technical feasibility translates into economic viability is still to be determined, and this determination will depend on the costs of alternatives.

CONCLUSION

In summary, the shift from a natural resource-based to a science-based agriculture creates a new set of uncertainties. We must invest enough in agricultural research to ensure that we have the capacity to meet future demands for food and other agricultural products, whether or not we use all of the capacity. The uncertainty increases when we consider the need to provide developing-country farmers with access to the new technologies.

Advances in agricultural production in the future will depend increasingly on scientific advances in laboratories in the developed world. Because biotechnology innovations are patentable, the private sector in the developed countries is making a major investment in biotechnology research. A new alliance is developing between the public sector engaged in basic scientific research and the private sector engaged in technology development. How will the developing world share in these advances? Is there a danger that they could increase their dependency on chemical fertilizer and then be left without an option when oil resources become depleted?

The lesson that we have learned from the Green Revolution is that technology tends to be very location-specific. Problems are solved when scientists work in the location where these problems exist. Furthermore, we know that a lack of basic scientific knowledge represents a serious constraint on the development of viable and sustainable technologies in many areas of the tropics.

The public-sector pipelines through which advanced scientific knowledge or biotechnology can flow are very poorly developed. For export crops, access to advanced scientific knowledge can be provided by multinational corporations. For the main food crops, access can come through the International Agricultural Research Centers and through national programs in larger countries such as India or Brazil. However, present linkages between these institutions and advanced laboratories in the developed world are very weak, and funding necessary to strengthen these linkages must come largely from developed country donor agencies.

Ruttan suggests the need for a truly global research system which would tie together the national and international research establishments in both the developed and the developing world (20). There will be a continuing need to upgrade the scientific and research capacity in the developing countries to ensure that these countries have the capability to utilize new scientific knowledge and adapt technology to local conditions.

Sustainability in an economic context implies a stable and satisfactory relationship between agricultural production and consumption. It implies a world population level or growth rate which is supportable on a long-term basis. It implies that negative by-products such as hazards from pesticides and fertilizers are controlled. Sustainability probably requires sufficient equity in access to production capacity and distribution to insure political stability.

The current period is fortunately characterized by the disappearance of world monopoly pricing in petroleum, and the rapid growth of energy-intensive productivity in agriculture. Our research agenda should be planned now in anticipation of the need for different agricultural technologies in the future.

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Transfer of Research Results into Practice in Czechoslovak Agriculture

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In the further development of the national economy—including the sector of agriculture and food—it is no longer possible to rely on extensive development of natural resources within the Czechoslovak Socialist Republic. Intensification is therefore the only feasible course in implementing long-term development programs. Such intensification has become necessary because of the increasing population; the need to use some farm land for mining, road building, and other non-agricultural purposes; and the expected expansion of protected water source areas and areas protected for cultural reasons. Scientific and technological development and the increased utilization of research results are now considered the principal basis for intensification and for increasing the effectiveness of food production in Czechoslovakia.

Therefore, in the last decade opportunities offered by science have commanded great attention among the central, regional, and district authorities responsible for the management of agriculture and food production, producers of farm machines, designers and planners, and farmers themselves. Within the management of agricultural production, accelerated and effective implementation of farming practices which reflect the results of science and technology is being purposefully planned and directed. This effort enjoys broad support and provides moral and material motivation.

The introduction of the results of science into practice is called "transfer". This refers to the transformation processes during which knowledge of an intangible nature changes into a new means of production or into applications-oriented information, methodological instructions, processes, and standards. In the area of food production these transformation processes and agricultural production techniques are of a multidisciplinary nature. They are dominated by the biological character of the production process with its variability, dependence on external conditions, and disharmony between the production technology and the working process. Agriculture also depends on other branches of the national economy for the supply of almost 60 percent of the necessary means of production, e.g., machines, chemicals, biochemical preparations and materials, building materials, and power.

The optimization, rationalization, and effectiveness of transferring research results into practice has commanded the attention of the central authorities in Czechoslovakia as well as of the organizations responsible for agriculture and food. This interest is both theoretical, (e.g., theory of management, information theory, systems analysis and synthesis, psychology, and sociology) and practical at all levels of management. Of course, no matter how sophisticated a system may be, it cannot work effectively if it is not supported by the initiative and activities of its users (i.e., agricultural enterprises), and by the interest of agricultural workers and their acceptance of new findings and new approaches.

With regard to food production in Czechoslovakia, the main instrument for the purposeful transfer of the findings of science to practice is the *Unified Plan of Development of Science and Technology in the Agroindustrial Complex for the Period of the 8th Five-Year Plan*, which is derived from the *Long-Term Program of Development of the Sectors Responsible for the Nutrition of the Population*. It includes scientific programs and tasks of basic and applied research, activities involving international scientific and technological cooperation, the creative initiative of the workers, and a number of other components of scientific and technological development.

The *Unified Plan* is left open to accommodate advances in knowledge. A chapter called "System of Planned Realization of the Results of Science and Technology in Agricultural Practice and Food Production" is an important part of the *Unified Plan*. This system includes the following factors which support rapid and effective utilization of new findings, adequately transformed, into practice.

- The so-called "primary realization" is used for broad implementation of new findings of a material and non-material nature. With support from the state budget or from the agricultural sector, primary realization is aimed at testing the suitability and effectiveness of new solutions in order to eliminate risks which would otherwise be borne by the agricultural enterprises. For the period 1986-1990 the *Unified Plan* includes 79 such pilot operations and 72 prototypes.

- Findings obtained from other countries undergo a similar testing procedure before they can be used in Czechoslovakia.
- Great emphasis is placed on designing and engineering because of the importance of novel technical products, building projects, software, and the like for the introduction of new scientific and technological results into agricultural practice.
- Long-term programs of scientific and technological development have been prepared at the regional and district levels for the management of agriculture and of "Science and Technology Development Funds" which can be used by agricultural enterprises on the basis of their profits to implement these programs.
- Responsibility and coordination within each agricultural sector have been entrusted to organizations called "production and economic units," which are in the form of trusts. For instance, the Oseva Praha Corporation is responsible for the production of seeds and planting material for crops and the State Animal Breeding Enterprises produces farm animal reproductive material.
- The central authorities coordinate findings of science and technology for implementation. Other findings become the subject of supplier/purchaser relations.
- Support is given to contract-based relations between scientific institutions and agricultural enterprises in reaching solutions in important fields of scientific and technical development. One of many examples is the cooperation between the South Bohemian Biological Center of the Czechoslovak Academy of Sciences and the Chelčice cooperative farm in research, development, and production of bioinsecticides.
- Accelerated implementation of the results of science and technology in agricultural practice is also encouraged through the material interest of the workers in terms of premiums and through other incentives.

Special attention is paid to other resources and means which can influence the effectiveness of scientific and technical development in agricultural production. These include, in particular, the initiative of the workers; the educational system; scientific propaganda and a system of scientific and technical information; and the involvement of selected advanced enterprises in the transfers. We believe that the utilization of these approaches significantly supports and accelerates scientific and technical development and the effective introduction of the results of research into practice.

The creative initiative and inventiveness of the workers are fully supported by the central authorities. We insist that agricultural enterprises support these activities. To solve particular agricultural problems, thematic tasks are announced every year. Under current law, enterprises must render financial and technical assistance to inventors and improvisers. A great deal of work on solving partial problems is also done by groups called "complex rational brigades." The results of the creative initiative of the workers are periodically presented to the public at national and regional exhibitions aimed at encouraging their widest utilization. In many cases these exhibitions help to find potential producers. For example, agricultural workers usually produce such novelties within their ancillary production programs.

The educational system and its effectiveness in encouraging scientific and technical development are secured by a network of special apprentice schools which prepare qualified workers, secondary agricultural schools which produce technicians and technologists, and agricultural and veterinary universities whose graduates are agricultural engineers and veterinary surgeons. Agriculture also employs graduates of non-agricultural universities. New findings of science and technology can be gained by all persons working in agriculture through various training courses and post-graduate studies organized by the Institutes of Education and Training of the Ministries of Agriculture and Food of the Czech and Slovak Socialist Republics. Experience has shown that the professional preparation of the workers is one of the basic prerequisites for effective introduction of the results of scientific and technical development.

Systematic scientific and technical propaganda is being developed for dissemination to the broad public and for winning the public's support for scientific and technical development. For instance, lectures of the School of Progressive Experience are regularly shown on television. There are also the publicist programs of Agricultural Year, Agricultural Magazine, and others. Publishing organizations offer a wide spectrum of agricultural books and periodicals. Great attention is paid to the development of the system of scientific and technical information, including international cooperation in this field. A network of agricultural information centers is in place, and an experimental terminal network reaching out to some of the larger agricultural enterprises is being tested.

Within the last decade a number of agricultural enterprises, both cooperatives and state farms, have reached the top standard of management with outstanding results of the implementation of the results of science and technology in practice. These advanced agricultural enterprises serve as examples of prompt transfer of science to practice. They serve as models of effective introduction of progressive technological systems and engineering services into wide application. At present, there are 198 "model" enterprises, including 136 cooperative, 45 state-operated, and 17 joint agricultural enterprises in both the Czech and Slovak Socialist Republics. Training centers for technicians and technologists at these agricultural enterprises are in the process of being established. All of these efforts will be further developed in order to accelerate the transfer of science to practice in Czechoslovakia, and new sources of acceleration will also be sought.

Agricultural Development and Environmental Research: Near-Term and Long-Term Research Priorities

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INCREASING AGRICULTURAL PRODUCTIVITY

Three major legislative acts created the educational, research, and outreach system in the United States which has contributed significantly to increasing agricultural productivity (4). The Morrill Land Grant Act of 1862 established colleges of agricultural and mechanical arts in each state to offer practical help for farmers through science and technology. The Act has been called one of America's great social inventions. In 1887, the Hatch Act was passed to establish agricultural experiment stations in association with the land grant colleges which would serve agriculture with research and testing. Finally, in 1914, Congress passed the Smith-Lever Act which appropriated federal funds to supplement state and county funds in order to establish a Cooperative Extension Service for providing rapid diffusion of scientific and technical knowledge and for serving as a feedback mechanism by which problems at the farm level could be brought back to the university, thereby facilitating a relevance of research to farmers' needs.

The history of U.S. agricultural productivity can be divided into four major periods: hand power, horse power, mechanical power, and finally, science power (Figure 1). The transitions from one form of power to another were marked by the Civil War, World War I, and World War II (6).

As Figure 1 illustrates, during the science power period—when

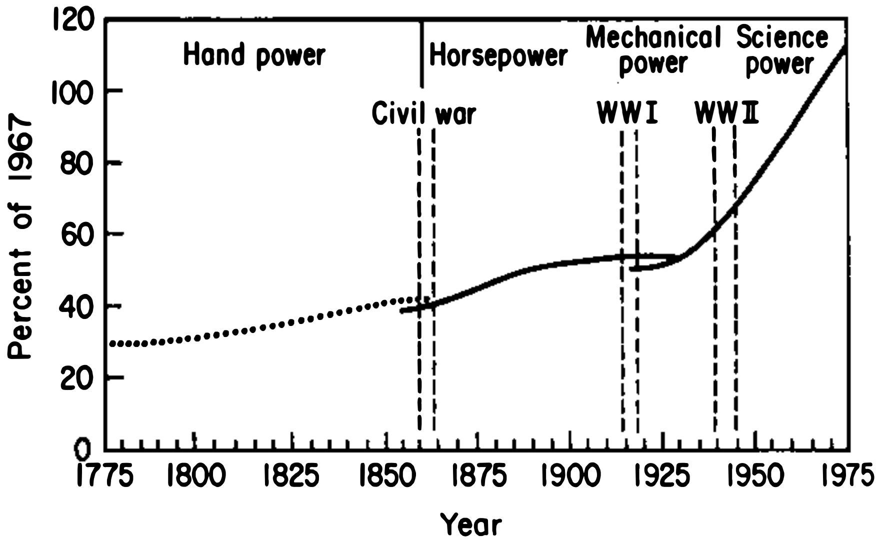

FIGURE 1 U.S. agricultural productivity growth during the past 200 years.

all three legislative acts previously mentioned were operational—dramatic gains in productivity were achieved. In their article "Economic Benefits from Research: An Example from Agriculture," Evenson, Waggoner, and Ruttan provided several indices to measure productivity from the 1950s to 1978 (1). As shown in Figure 2, land productivity increased at a rate of nearly two percent per year. There was a dip in productivity in the early 1970s when, in part, less productive land was removed from the soil bank in response to world grain shortages. The index of labor productivity is widely used in agriculture and industry. Figure 2 also shows that since 1950 labor productivity has grown far more rapidly in agriculture than in the non-farm sector. Total productivity—which is calculated by dividing the index of farm output by the index of total farm input—has also grown rapidly since the 1950s. In the thirty-year period from 1949 to 1979, scientific and technological innovation increased agricultural output by 85 percent with no change in the aggregate level of agriculture input.

World War II helped accelerate the true transformation of agriculture in the United States. The shortage of labor pulled many of those underemployed on the farm into the factory, service jobs, or other urban jobs, providing parity wages for those who stayed on the farm for the first time since 1920. During the war, farmers received special exemptions for fuel and tires, and by using all available machinery, produced 25 percent more food and fiber with 25 percent fewer workers. Also, new chemicals such as herbicides and organophosphate pesticides, produced in association with the war effort, became available for agricultural use. A measure of the increased use of science and technology power is shown in Figure 3 from a recent General Accounting Office (GAO) Report, *U.S. Food: Agriculture in a Volatile World Economy* (2). Between 1930 and 1980, labor input declined by more than 80 percent. Meanwhile, the use of mechanical power rose 200 percent, agricultural chemicals 1,900 percent, and seed almost 300 percent. Crop land as an input remained almost constant.

In addition to increased efficiency of production from the application of the new tools provided by science, tax laws encouraged expanded production capacity through the substitution of capital for

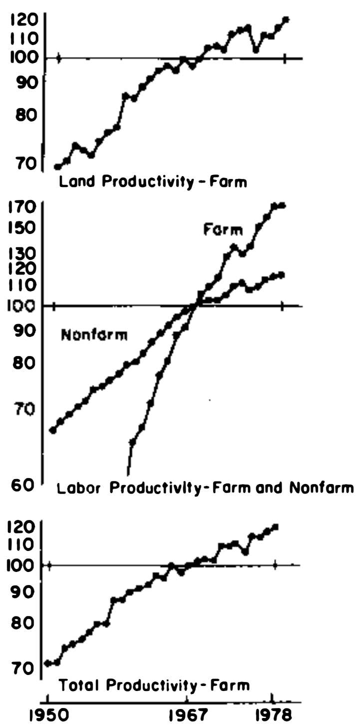

FIGURE 2 Productivity measures (1967 = 100).

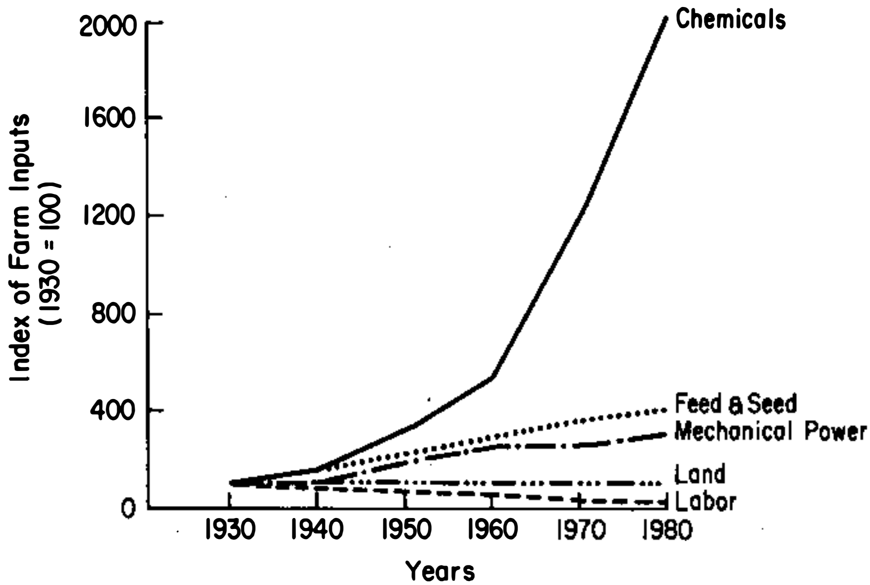

FIGURE 3 Changing inputs in agricultural production.

labor and land. Examples of the tax provisions include tax advantages for expanding many capital investments, capital gains treatment of certain livestock returns, investment tax credits, and accelerated depreciation rates. In other words, federal policies provided an incentive to use the new science and technology and consequently contributed substantially to the rapid increase in productivity.

A most dramatic example of the interplay between science and government policy is seen in the tremendous growth of agricultural productivity in China. In seven years China has gone from a country which faced shortages in grains and fiber to an exporter of both. The agricultural sciences in China have been extensively rebuilt since the Cultural Revolution, when government investment and World Bank loans which have permitted the exchange of scholars and the renewal of the research infrastructure. But equally important was the government policy which changed the production unit from the commune to the individual household. After a household meets a specified quota of crops or animals, the surpluses can be sold to the state at higher prices or sold on the open market. The combinations of science and technology and incentives have facilitated an agricultural revolution in China.

What have the benefits and costs to U.S. society been during this period of rapid increase in productivity due to science power? One benefit of increased productivity or increased production efficiency is that costs to the consumer have been reduced. In 1950, the average U.S. household spent 22 percent of its income for food. Today, approximately 15 percent of household income is spent on food.

Another benefit of increased productivity, at least initially, was the release of labor from food and fiber production to work in other sectors of our economy. As shown in Figure 4, the greatest decrease in farm workers was in the category of farm family labor, often the unpaid or underpaid sons, daughters, and spouses of the average farmer. Today approximately three percent of our population is directly involved in on-farm production of food and fiber.

But in addition to the release of farm labor for work in other sectors of the economy, there was also a dramatic decrease in the

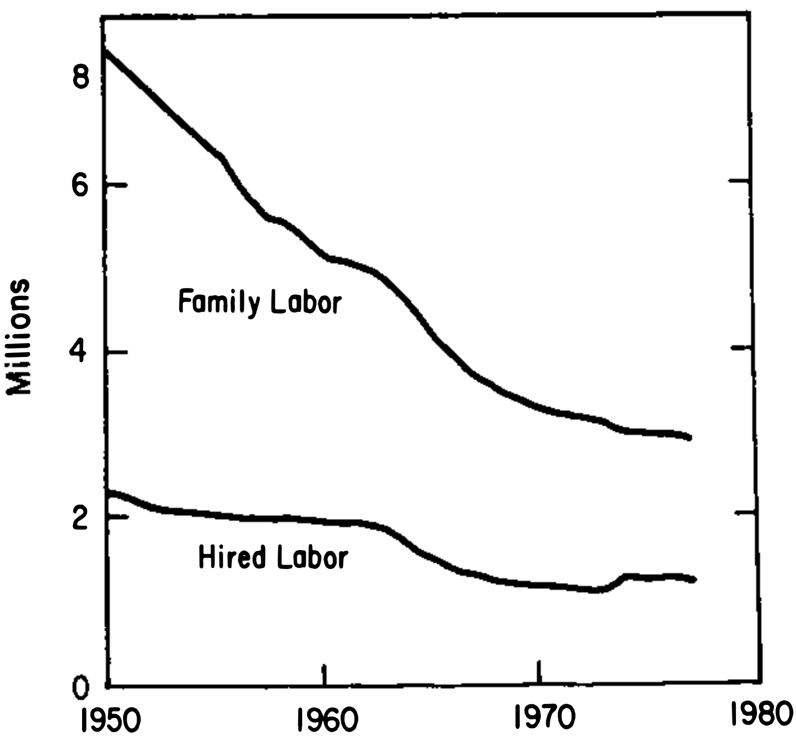

FIGURE 4 Number of farmworkers.

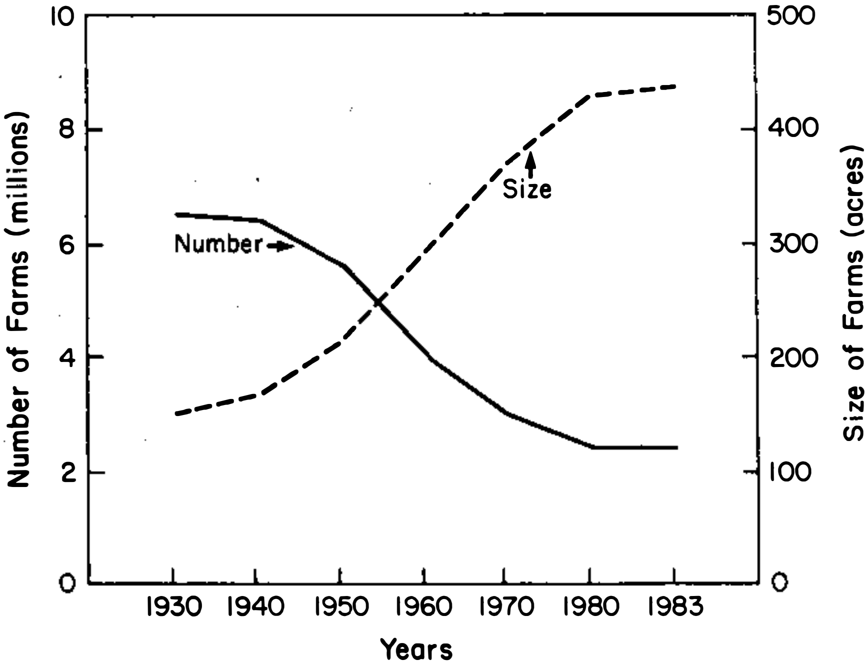

FIGURE 5 **Number of farms compared with farm size.**

number of farms and an increase in farm size, as shown in Figure 5. In 1930, there were 6.3 million farms, averaging 157 acres in size. In 1983, there were 2.3 million farms averaging 437 acres. Many critics blame science and technology for the decline in farm numbers and the growth of farm size.

While it is true that science and technology have made larger farming operations possible, it is incorrect to place all of the responsibility for the decline of farm numbers and the growth of farm size on science. Economic factors such as economies of scale associated with large purchases, policy issues discussed earlier—such as investment tax credits, accelerated depreciation rates and government price supports, and other farm programs—all contributed to the decrease in the number of farms. In the current economic climate of depressed farm prices and high interest loans caused by the large national debt, the number of farms will continue to decline and the average farm size increase.

Another criticism of the impact of agricultural technology is that it has increased the vulnerability of U.S. farmers to externalities. While farmers in the 1930s were largely self-contained, they now purchase about 75 percent of their production staples—such as pesticides, machinery, fuel, improved varieties, and fertilizers—from outside sources. Extensive purchase of production supplies from non-farm sources requires that farmers maintain adequate cash flow and be able to obtain operating credit. This situation makes the farmer more vulnerable to economic externalities while still being subjected to the vagaries of weather and the marketplace.

ENVIRONMENTAL CONCERNS

Perhaps one of the most serious challenges facing agricultural technology is the impact that the technology has had on the environment. As seen in Figure 3, the use of agricultural chemicals grew by 1,900 percent in the 50-year period between 1930 and 1980. The appreciation of the adverse effects of agricultural chemicals—particularly on non-target organisms—has grown dramatically, as has the ability to detect and measure these effects.

Perhaps as late as World War II, U.S. society was little concerned with agricultural scientists. There was general support for the idea that the most advantageous way for society to benefit from science was to allow scientists to follow the logic of their disciplines. There seemed to be vast reserves of land and water and an abundant supply of cheap energy. Any adverse effects of technological change were muted or absorbed by the abundant resources and an expanding economy.

However, as the population grew and the resources of land, water, and energy and the availability of jobs became limiting, society began to take an interest in what was going on down on the farm and in the university. Interrelations became clearer. John Muir, founder of the Sierra Club, may have provided the first definition of ecology by stating "when we try to pick up anything by itself, we find it hitched to everything else in the universe." One of the first expressions of society's concerns about its environment and impact of technology was initiated in 1962 by Rachel Carson's book *Silent Spring*, which brought to the public's attention the potential impact of chemicals used to control pests of plant, animal, and human life. The space age was here, and views of the earth from spacecraft underlined how finite our resources really are.

Increased sophistication in instrumentation led to better detection of chemicals in the environment. Measurements used to be in parts per thousand, then parts per million, and now parts per billion and trillion. Awareness that some compounds can cause genes to mutate and/or stimulate the initiation of cancer has increased the concern for the introduction of synthetic and even naturally occurring compounds into the environment, food, and water. In November 1986, California citizens overwhelmingly passed Proposition 65 which imposes large fines and possible imprisonment for anyone introducing a possible carcinogen into drinking water supplies. If a citizen reports such an action, he or she can receive 25 percent of the fine.

Universities have responded to these concerns. Many former colleges of agriculture are now colleges of agricultural and environmental sciences, and there has been more than just a name change. At the University of California at Davis, for example, there are departments of environmental toxicology, a division of environmental studies, and an institute of ecology. Integrated pest management programs have been developed to integrate all available pest control strategies—biological control, genetic resistance, crop rotation, and other management techniques, as well as selection of more targeted, biodegradable chemicals. Hopefully, the new tools provided by recombinant DNA technology or genetic engineering will help speed understanding of pest/host interactions in order to develop new control strategies and also speed the development of genetic resistance.

Beyond the traditional objective that technology must be profitable for the user, additional criteria in agricultural research and development must be applied. Included are energy efficiency, acceptable long-range physical impacts on the environment, minimization of health and safety risks, and acceptability and/or mitigation of social costs.

RESEARCH PRIORITIES

Given this background, what are our short- and long-term research priorities for environmental research? First, it is necessary to better anticipate the risks associated with new technology, and to view food and fiber production as a system rather than as a single crop in a single season.

The U.S. Department of Agriculture (USDA) Joint Council on Food and Agricultural Sciences established the following fiscal year

1988 research priorities for research, extension, and higher education (7):

- Enhance profitability in agriculture;
- Expand biotechnology to enhance the benefits from plants and animals;
- Improve water quality and management;
- Strengthen the development of professional and scientific expertise;
- Enhance productivity and conservation of soils;
- Expand domestic and foreign markets and uses for agricultural forest products;
- Preserve plant germplasm and genetically improve plants;
- Improve human nutrition and the understanding of diet/health relationships.

Under the first category of enhancing profitability in agriculture are the following specific criteria for research, extension, and teaching:

- Develop total farm production, management, and marketing systems that will sustain the long-term productivity, profitability, and competitiveness of agricultural operations;
- Expand holistic educational programs using multidisciplinary teams, results demonstrations, computer programs, and individual assistance to accelerate the adoption of appropriate technologies, and organize and tailor them into individualized systems that are viable, realistic, and economically feasible;
- Encourage producers to adopt technology and practices that improve efficiency, cut the cost of inputs, and reduce animal and plant losses while increasing product quality and improving net income.

The second priority, expansion of biotechnology to enhance the benefits from plant and animals, is an area rich in potential applications to reduce the environmental impact of agricultural production.

Recombinant DNA techniques provide the tools to better understand host/pathogen or pest interactions which can lead to new pest control strategies. It may be possible to speed the rate of developing plants resistant to abiotic environmental stress such as salt tolerance and to biotic stress caused by diseases and insects. The identification of the *nif* genes associated with biological nitrogen fixation raised the hopes that the range of organisms could convert atmospheric nitrogen to ammonia and other nitrogenous compounds. Although this objective has yet to be realized, the efficiency of the existing nitrogen-fixers has been increased, and there is a better understanding of the complex set of interactions that take place in a symbiotic relationship. The whole area of rhizosphere dynamics—including the presence of microorganisms that reduce diseases and insects and enhance nutrient uptake—is a high priority research area in which the tools of recombinant DNA will play an important role. An example is the transfer of the gene from *Bacillus Thuringiensis*, which regulates the production of a protein toxic, to tomato hornworms to *Pseudomonas fluorecens*, which lives in association with corn roots in order to provide black cut worm control. Microorganisms can also be selected or modified to biodegrade toxic substances that have accumulated in the soil. Finally, an important area of research in the biotechnology area is risk assessment to determine the impact of the release into the environment of recombinant DNA-modified organisms.

The third major priority is to improve water quality and water management. Included is the need to increase available water supplies through the application of improved watershed management practices on forests and rangeland. Improved management practices are also required to prevent salinity and to reduce the energy requirements in the movement of water. An area of growing concern in irrigated agriculture is the safe and economic disposal of drainage waters which can contain salt, selenium, heavy metals, and pesticides.

Specific recommendations for science and education in this area include:

- Assess the impact of water pollutants including acid rain on livestock, crops, and forest and aquatic systems;
- Formulate improved management systems that better utilize chemicals, minimize erosion, and reduce the movement of pollutants to surface and groundwater;
- Develop economic practices to increase water yields from forests and rangelands;
- Increase efficiency of irrigation water use;
- Increase understanding of relationships between crop production systems and the quality of groundwater and surface waters;
- Improve soil and water management systems to reduce the impact of salinity and improve irrigation efficiency;
- Design systems for the safe and economic disposal of contaminated irrigation waters;

- Develop and implement coordinated interdisciplinary activities concerned with the nature of water resources; the importance of water and human health and nutrition; the proper use, handling, and disposal of agricultural chemicals; and the impact of various land uses.

The next priority area which has a direct impact on the environment is to enhance productivity and conservation of soils. Soil resources are a primary determinant of the productivity of U.S. crop, range, and forest lands. Soil compaction, salinity, loss of organic matter, atmospheric deposition, and restricted drainage reduce productivity. Accelerated soil erosion caused by wind and water is viewed as a national problem which not only affects productivity but also creates sediment with losses to recreation, fisheries, and water facilities.

Specific science and education programs in this area include:

- Improve understanding of the relationship between erosion and soil productivity;
- Improve crop, range, and forest land management through new, lower cost, resource-conserving plant production systems. For example, conservation tillage has been widely adopted because of strong economic incentives such as lower labor, machinery, and energy requirements. At the same time it promotes soil conservation, fertility management, and reduced soil erosion from wind and water when used in conjunction with other conservation practices and shelterbelts.
- Promote the concept of new plant and animal production systems to accelerate the adoption of cost-effective, economically feasible conservation practices in order to reduce the impact of soil erosion on both producers and consumers and to encourage the shift of marginal lands to conservation uses.

National policies play a very important role in this priority area. For example, price supports of small grains encourage the planting of fragile lands. Therefore the public pays twice: once for subsidies for the costs of the production and again for the costs of the environmental impact of that production. On the positive side, 1985 national legislation includes conservation provisions to reduce soil erosion, improve water quality, improve fish and wildlife habitats, and remove incentives to convert wetland and grassland to crops.

All farm land will be classified as to its potential for erosion. If a farmer wishes to farm highly erodible land (about 25 percent of total farm land), the farmer must have a conservation plan developed and approved by the USDA Soil Conservation Service by 1990 and fully implemented by 1995. If a plan is not developed, the farmer will lose eligibility for a number of USDA programs such as commodity price support loans, Farmers Home Administration loans, and federal crop insurance.

Another priority area that has important environmental implications is the preservation of plant germplasm and the genetic improvement of plants. The understanding and appreciation of the sources of desired traits and the genetic basis of inheritance will provide geneticists, biotechnologists, and breeders with the ability to develop species, varieties, and strains that are more resistant to pests, tolerant of environmental stresses, and capable of utilizing beneficial microorganisms. To take advantage of the powerful new tools for manipulating genes to achieve these goals, efficient systems for collecting, preserving, evaluating, and distributing germplasm are essential.

Special research topics in this area include:

- Develop innovative procedures for preserving and evaluating germplasm such as cryogenic storage and genetic mapping;
- Determine the genetic basis for minimizing damage caused by pests such as nematodes, pathogens, insects, and weeds;
- Establish the genetic basis for tolerance to environmental stress;
- Determine the genetic basis for characteristics which determine superior physiological and morphological traits that will facilitate new cropping systems;
- Develop conservation programs to reduce the loss of germplasm resulting from new farms, roads, housing, and industry. The tropical forests in Central and South America are an area of particular concern because many genera and species of wild plants are being lost, resulting in a decrease in the earth's total photosynthetic capability.

Three other areas of research which are important priorities for agriculture and the environment are integrated pest management, sustainable agricultural production systems, and global tropospheric chemistry. Improved pest management technologies and educational programs are needed to employ economically feasible and environmentally safe systems for control of disease, insects, nematodes, and weeds. Essential components of a successful system are the ability to predict and control pest and disease occurrences (often using computer-based models), statistical sampling techniques, biological control and cultural techniques, and precision application of pesticides which are highly specific to the target pest.

The foregoing discussion divides problems into definitive areas, such as soil, water, germplasm, and integrated pest management. Such an approach is often necessary to comprehend and define a problem and to develop a strategy to solve it. However, the total system of food and fiber production is in a constant state of interaction with the environment. In order to better appreciate these interactions and, hopefully, to better anticipate the consequences of particular actions, a research, teaching, and extension program in sustainable agriculture has been developed which is described as a holistic approach to the food and fiber system (5). Areas of research will include the effects of different cover crops on soil management and fertility; intercropping studies comparing planting times, spacing variety combination, pest relationship, and ease of field operations; organic management systems for specialty crops appropriate for small-scale operations; and the integration of livestock and crop production.

Finally, an area of research which needs more attention by scientists engaged in agricultural and environmental research is global tropospheric chemistry (3). The atmosphere is an ever-changing, physically and chemically active environment wherein oxygen, carbon dioxide, and nitrogen are fuels and food for human, animal, and plant activity. The troposphere, the lowest region of the atmosphere containing 80 percent of the atmospheric mass, is an integral part of the biosphere and an essential component of the global life-support system. Although the atmosphere is self-cleansing—primarily through chemical reactions based on the abundant supply of molecular oxygen—a variety of measurements made over the past few years and decades indicate that the global atmosphere is changing.

It is not certain that all of these changes are due to human activities but some, such as the buildup of carbon dioxide, appear to be. Recent measurements of atmospheric methane show it is presently increasing globally at a rate of over one percent each year. Synthetic chlorofluorocarbons are believed to be partially responsible for the decrease of ozone observed at the South Pole which leads to an ozone hole during the Antarctic spring.

The need to do research concerning acid rain has been recognized, but there should also be concern about the potential long-range effects on climate caused by the increase of carbon dioxide and a possible increase in ultraviolet light if ozone is in fact decreasing.

Major accomplishments have been made through science and technology in the development of a highly productive food and fiber system. But society is increasingly questioning the cost of this productivity, particularly in terms of the quality of the water, soil, and air. The conclusion is that the costs are outweighing the benefits. A full research agenda is in place to ensure that in the long term an adequate supply of food and fiber will be provided but produced in a way that will ensure that the system can be sustained for the benefit of future generations.

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Immediate and Long-Term Research Priorities

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The complex of environmental problems has been developing very rapidly in recent times, and the base of scientific knowledge has developed in two phases. The first phase was the recognition of the depth of ecological problems. At this level science and research focused mainly on the investigation of human impacts on the environment and on the search for possibilities for protection and, in some cases, improvement of the environment. These efforts were extremely important, particularly in revealing the very essence of the phenomena of concern and the undesirable trends of their development. Such research contributed substantially to the opinions being adopted by the general public on environmental issues.

Emotional and alarmist views prevailed in the initial social reaction to ecological problems. Nevertheless, in the course of time more realistic problem-solving approaches connected with the application of scientific knowledge gained popular support. It has become clear that solving present ecological problems requires a special science for framing a theoretical, methodological basis to rationalize, optimize, and harmonize the interactive processes between man and the environment, and to bring together the objective needs of ecological laws with the principles of social organization. Key political decisions in all spheres must respect the basic laws of ecological interaction between society and nature. Achieving optimum harmony between social development and the state of the environment should be considered the main goal.

In many European countries this process was completed in the last few years. As principal factors affecting the further development of our living standard, environmental considerations were embodied in the plans for industrial and social development in these countries. Attention was given mainly to the possibilities for stopping environmental deterioration and for creating the preconditions for environmental improvement. This area has received considerable financial support.

Research efforts have also brought together various techniques to fulfill these tasks. In industry, especially in the area of scientific/technological development, research is aimed at controlling the harmful effects of technological processes (e.g., development of methods for absorption of harmful substances generated as wastes by various technological processes, which are then either utilized or neutralized). At the same time, research efforts are currently addressing the problems of utilization of solid and liquid communal wastes, and of proper disposal of non-usable wastes. Despite the fact that some measures are being taken and appropriate devices have been constructed, there are still many problems which have to be solved.

It is therefore necessary to constantly revise proposed solutions and to seek new approaches in the continuing process of changing technologies which cause excessive environmental loads and replacing them with new ones which are less harmful or, ideally, harmless. These facts may be summed up in a single conclusion: Environmental problems penetrate into all fields of technology, chemistry, and related research.

In the sphere of economic sciences and technological/economic information there are many subjects related to environmental improvement such as the improvement of production effectiveness, organization, and product quality, and the conservation of raw materials and energy. Such trends contribute to decreased demand for these products as well as to waste reduction.

The role of agriculture in the environment is seemingly contradictory. Agriculture is greatly affected by environmental degradation due to deterioration of organisms which are vital to agricultural production. Therefore, it is necessary to continue investigating and monitoring the changes in the environment, including pollution by foreign substances, while studying the impacts on organisms and the possibilities for protection against these impacts. Further, the selection and cultivation of more resistant species and the pursuit of further measures aimed at reducing negative effects are needed. Research on bacteria, fungi, and higher plants which accumulate heavy metals and other compounds is currently being conducted.

Paradoxically, agriculture has also become one of the negative factors contributing to deterioration of the environment, and this negative impact intensifies with increased agricultural production. Interestingly, such an increase is not contrary to ecological laws. Maximum yields of biomass enrich the air with oxygen, draw nitrogen from soil and prevent it from entering watercourses, and maintain the cycles of various biogenous elements such as carbon. The problem is that while in natural ecosystems this process has a regular course, the same process leads to accumulation in agricultural areas due to technological devices such as mechanization and chemical use, or to landscape changes such as soil reclamation. Ecologists therefore concentrate mainly on the fundamental resources supporting agricultural production such as topsoil, which is a new element in the development of the biosphere, is cultivated by human activity, and is therefore very vulnerable. In this case the process of self-renewal is out of the question.

Such a situation prevails within the whole biosphere, both at the local and global level. Man has become responsible for nature, and this fact must influence the principal orientation of science, both in the natural and social sciences. Physics, chemistry, and biology can no longer be restricted to the investigation of nature merely "as it is" but rather "as it may be," i.e., the phenomena and processes that are initiated and their consequences under specific conditions. It is necessary to investigate not only the impact of human activities and the disturbances of natural conditions but also how to manage these activities to achieve harmony in the development of nature and society.

Therefore, the principles for solving ecological problems will be more scientific if they are multidisciplinary, based not only on application of biological and ecological sciences but of other sciences as well. This knowledge should be not merely accumulated and classified but also utilized. Research results should yield syntheses not only drawing on all scientific disciplines (natural, technological, agricultural, forestry, medical, and social sciences) related to ecological problems but also taking into account specific projects aimed at solving these problems.

Long-term research is aimed at the recognition of the structure and function of landscape systems and their utilization toward optimum management of a region. This calls for study of the social, technological, and natural processes affecting mutual relations of human populations and nature. At the same time, it is necessary to concentrate on the problems of the devastated areas of the landscape. Recognizing the potential for regeneration and reclamation is helpful in determining the possibilities for renewal of natural conditions in regions with disturbed ecological conditions, and also in the prevention of negative impacts in regional systems with heavy technological loads. Therefore, interactions between the environment and human populations and the role of man during the development of socio-ecological landscape systems should be considered in preventing anthropogenic ecological crises in the landscape.

A thorough knowledge of nature—from the simplest organisms to species, populations, communities, and ecosystems—as well as knowledge of natural processes, developments, and disturbances are fundamental to ecological studies. Investigations of foreign, especially toxic, substances and their transport, accumulation, and impacts have become more and more important. Application of biotechnology offers numerous new possibilities. Near- and long-distance transfer studies play an important role, especially those related to air pollution which involve detection and monitoring of these substances. Above all, it is necessary to study the effect of low levels of environmental pollutants, since their dangerous effects may remain hidden for a long time and manifest themselves only after accumulating to a significant extent when it is usually too late to apply effective countermeasures. In this regard, biodiagnostics and biomonitoring can be very reliable, especially since the responses of sensitive organisms to pollution are relatively rapid. It is possible to affect organisms or even populations and communities whose reactions to pollutants are either selective and specific, or general and non-specific but still apparent. Many of these methods such as monitoring of mutagens are so complicated that they will probably always remain at the level of basic research.

The increase and management of biomass production in an anthropic, artificially altered landscape, or in a landscape under anthropogenic pressure, is another very important research problem. It is not just the part of the landscape used by man but also the relatively unimpacted natural landscape which is of concern. No landscape, not even the nature reserves, can be left to completely spontaneous development. The influence of man is so strong that it should be viewed as global; therefore even areas of unaffected nature, if any still exist, must be actively protected.

Research on self-purification processes in specific biosphere components such as soil and water will yield valuable knowledge helpful to the initiation and support of this process. Until now, biotechnologies have seldom moved beyond production for use by man, and their use for nature protection has been sporadic (e.g., fermentation bacteria injections at crude oil leaks). These technologies have been used even less frequently to form new ecosystems in localities where original relationships were disturbed so severely that the natural ecosystems decayed. There are obviously many tasks for research in this field.

Every new or developing scientific field is based on new methodologies, and ecology is no exception. Remote sensing systems using airborne and spacecraft devices have proved to be very promising in this regard. This technique provides extensive information on a given area and its environmental situation, including phenomena which cannot be detected by terrestrial observations. Thus, it provides a better classification of phenomena and facilitates the systems approach. Despite the fact that we are still far from able to elaborate a comprehensive cybernetic model of the environment, it is possible to produce models which solve particular questions, although their applicability is limited.

These methodological approaches are closely connected with information systems not only in terms of information accumulation and classification within particular data bases, but also in terms of the use of such information. The primary issue is defining environmental data which can be quantified and embodied into technical-economic information systems, and which are of principal importance from the viewpoint of short- and long-term plans of development.

As to land use, agriculture prevails over forestry but loses out to industry and residential agglomerations. There are only a few possibilities left for the preservation of original, unaffected parts of nature. Even in nature only partially disturbed by anthropic impacts, it is possible to observe a relatively rapid change in the blood count of a man having previously lived in the unfavorable environment of an industrial agglomeration. In addition, nature provides the resources necessary for the ecological stability of the landscape. These resources are used by man either unconsciously or with a special intent, even for creating artificial systems and biological production technologies.

Finallly, we must mention the aesthetic and cultural aspects. The protected areas network has developed randomly, mostly in areas with conflicting interactions of forestry, agriculture, industry, and residential agglomerations. Nevertheless, such a state cannot be considered as ideal. It is necessary to apply the results of landscape planning, and thus achieve the inclusion of important landscape elements in regional plans.

All these questions require a global perspective which can yield corrections of local approaches. The shift toward global level observations will mean above all the application of interdisciplinary approaches to ecological problems, from astronomy to social sciences. Generally, it will mean more intensive international scientific cooperation.

We should mention several international scientific programs, such as the Man and Biosphere (MAB) program as well as programs of other governmental or non-governmental international organizations. The important topic of the SCOPE International Geosphere-Biosphere Program (IGBP) could serve as a model of a broad, interdisciplinary approach. This interdisciplinary approach, especially between the social and natural sciences, is used even in the MAB program. It would be extremely useful to evaluate all of these programs and on this basis determine the fundamental principles of international scientific cooperation in the field of environmental protection.

Recent Developments in Integrated Pest Management

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PESTICIDES AND THE ENVIRONMENT

Agricultural crops in the United States are the target of several thousand pests including insects, plant pathogens, weeds, nematodes, and vertebrates. Prior to the Second World War, relatively few chemicals were used for pest control and most were classified as either botanical or inorganic, depending on their origins. Production of pesticides in 1945 was less than 90 million kilograms. The development of synthetic chemicals during the war such as DDT, parathion, malathion, and 2,4-D resulted in a large increase in the production and use of pesticides. During the next 40 years, pest management became increasingly dependent upon chemicals, and pesticide production in the United States increased by a factor of ten. Despite this rise in pesticide use, it is estimated that approximately one-third of U.S. agricultural production is lost prior to harvest by the action of pests.

Pesticide use worldwide has brought about many unforeseen environmental problems which affect not only the agricultural community but the general population as well. Problems affecting agriculture include pesticide resistance and secondary pest outbreaks. More than 350 species of insects, mites, and plant pathogens have developed genetic strains which can survive the application of one or more classes of pesticides. To control these resistant pests, higher rates of pesticides and more frequent applications are often used. At the extreme, when control of the pest by any method is no longer possible, production of the crop in an affected area may cease. Because pesticides kill beneficial organisms in addition to target pests, organisms that were under natural control may increase to damaging levels, requiring further pesticide intervention. Such a situation is referred to as a secondary pest outbreak.

Pesticides have come to be regarded as a threat to the environment and to human health by many individuals and organizations. There is reason for such concern. Some pesticides are highly persistent and can be found in the environment years after their use has ceased. Others can move readily through soil or water to become translocated beyond their original site of application.

DDT is an example of a highly persistent pesticide which enjoyed wide agricultural use. DDT entered the food chain at microorganism levels, becoming concentrated in the fatty tissue of organisms at higher trophic levels. In response to research relating DDT to abnormally thin-shelled eggs in birds and to cancer in laboratory animals, the U.S. Environmental Protection Agency (EPA) banned its use in 1972. However, DDT residues can still be found in the environment.

Dibromochloropropane (DBCP) was a pesticide widely used to control nematodes. In 1977, DBCP was found to cause sterility in male workers exposed to the pesticide during its production. Subsequently, DBCP was found in wells in some agricultural areas where it had been used. Apparently, DBCP could move through the soil to enter underground water supplies. Again, EPA moved to halt the use of this pesticide.

About 40,000 people are treated for pesticide poisoning each year in the United States. The actual number is not known because most cases do not involve acute toxicity, and symptoms mimic those of common maladies. Most acute poisonings occur because of worker exposure in either the production or the application of pesticides. In response, there has been increased regulation to ensure the safe use of pesticides.

INTEGRATED PEST MANAGEMENT

Recognition of the problems associated with the use of pesticides has brought about the development of a systematic approach to controlling pests in the agro-ecosystem. Integrated Pest Management (IPM) is an interdisciplinary approach using multiple methods to maintain pest populations at tolerable levels. Developing an integrated pest management system requires an understanding of crop and pest development and their interactions. It also requires knowledge of available control tactics. Both crop and pest development are directly impacted by environmental, cultural, and biotic factors. The responses to such factors are not well understood.

Research on plant growth is an essential prerequisite to development of an IPM system. Plants respond to temperature and light by producing products of the photosynthetic reaction. These products are used by the plant to produce more leaf area, more structures on which to hold the leaf area, more root mass, and ultimately reproductive structures. Well-watered and properly fertilized plants complete this process more efficiently. Plants store excess photosynthetic product for periods when production does not exceed demand. In the case of perennial plants this excess product is used for renewal of leaf area during the subsequent season.

Man cultivates plants either for their biomass or for their reproductive structures, depending on the crop. Pests compete with man for the plant structures and can injure plants by removing their photosynthetic area, damaging their structure, reducing their nutrient and water uptake mechanisms, or interfering with their reproduction. The importance of plant injury resulting from a given pest is dependent upon the plant structure damaged, the extent of the damage, the relationship of the plant structure to growth and development at the time of damage, and the intended use, if any, by man of the plant structure.

Pest population abundance is influenced by weather, available resources for growth and development, natural enemies, and the intervention of man. The abundance of a pest and the extent of the injury it causes at critical periods of a plant's development are key factors in determining when and if control actions should be taken.

PEST CONTROL ADVISORS

Application of IPM principles requires specialized training. Although growers in the United States are fully capable of learning and then applying these principles and tactics, many growers, especially in California, are relying increasingly upon guidance from professional pest control advisors in making pest control decisions. Pest control advisors must understand how pests, their natural enemies, and the crop interact with each other and also respond to changes in weather and management practices. They establish systematic field monitoring programs and take appropriate pest management actions which are based upon pest and natural enemy population abundance, crop maturity and health, and established control action thresholds. In California, pest control advisors must pass an examination to be licensed by the state and must take continuing education classes to renew their licenses.

Several studies have shown that pest control advisors utilizing IPM principles can reduce the level of crop damage, reduce the amount of pesticides used, and increase the net economic return to growers.

QUANTIFYING PEST POPULATIONS

Thresholds

The application of appropriate tactics to control pests requires that the impact of the pests be determined. An assumption of IPM is that some level of pest infestation can be tolerated and that the crop system can be managed to keep the pest population from exceeding an injury level with unacceptable economic consequences. The approach varies with:

- the relationship between the pest infestation and crop yield or quality;
- the cost of the pest control tactic;
- the amount of physical damage that can be prevented by the control measure;
- the monetary value of the portion of the crop saved by the control measure;
- the cost associated with failure to control the reproduction of the pest and the future consequences resulting from the residual population.

Some pests in park and recreation areas and in urban environments where they can affect public health are managed solely for economic reasons. In these situation, threshold levels vary directly with concerns over public health and welfare.

Pest Monitoring

Pest populations vary seasonally, geographically, spatially in a field, and spatially on a host because of various biotic and abiotic factors. It is usually not possible to sample all the pests in a given situation. Therefore, the abundance of a pest must be estimated by representative sampling. Applying principles of sampling to the monitoring of pest populations in the field requires:

- knowledge of the organism's distribution;
- a defined sampling unit;
- a practical and repeatable sampling method;
- an optimal sample size at a given confidence level with acceptable levels of error;
- a defined pattern of sampling.

A considerable amount of research has been conducted recently to improve the reliability and reduce the time of pest sampling. This research involves absolute sampling to provide estimates of the total population of an area, which can be accomplished by counting numbers of organisms directly on the sampling unit or by removing all organisms from a definable sampling area for counting. Devices that can be used to remove organisms include suction traps and rotary nets for aerial samples; beating devices, suction traps, emergence traps, brushing, and washing machines for foliar samples; and core samplers and emergence traps for soil samples. Relative sampling also provides estimates of population density that cannot be related to total density of organisms in a specific area, but rather only to other such samples. These relative population estimates can be useful in detecting the occurrence of an organism and its relative abundance seasonally. Examples of such devices include sweep nets, sticky traps, water-pan traps, pitfall traps, light traps, and pheromone traps. Relative sampling methods are especially useful when they can be calibrated to an absolute method, or when they are used with phenological models of pest development.

Sample size is dependent upon the variance between samples in relation to the mean value of the organisms that are counted. It is also dependent upon the confidence level and degree of precision desired. If more precision is required, more samples must be taken. This has a direct impact upon the time and expense of the monitoring program. Methods used to reduce monitoring time while maintaining a given level of reliability include binomial (presence/absence) sampling—as opposed to numerical sampling—and sequential sampling.

Meteorology

Weather controls many of the growth and developmental responses of pests and crops. Knowledge of temperature and precipitation can be used in some cases to accurately predict their development. In general, growth rate is dependent upon temperature. More accumulation of heat results in faster development within specific thermal thresholds. Physiological time expressed as degree-days is a measure of accumulated heat.

Several phenological models which are based on physiological time are being widely used in the management of pests and crops. Some of these models are very simple, providing information on the timing of such events as emergence after wintering and subsequent population dynamics. Others provide information on growth and maturation. Examples of insects often managed using phenology models include the oriental fruit moth (*Grapholitha molesta*), the codling moth (*Laspeyresia pomonella)*, and the tomato fruitworm (*Heliothis zea*). Examples of crops managed with such models include tomatoes for processing and cotton.

Disease prediction typically requires information on periods of wetness and innoculum density in addition to temperature. Examples of diseases for which predictive models are available and commonly used include apple scab (*Venturia inaequalis*), late blight (*Phytophthora infestans*), and early blight (*Alternania solani*).

Technological advances in electronics have made the acquisition and use of weather data more efficient. Automatic weather stations and data loggers with probes that sense various meteorological parameters are available and are being used by public agencies and by some medium to large farms to gather and store weather information for use in making management decisions. In addition, at least three private companies have combined automated meteorological data acquisition with computer programs for specific applications and are marketing these microprocessor-based products as pest management tools for farmers and pest control advisors.

MANAGEMENT TACTICS

Tactics available for managing pests are generally divided into those that involve pesticides and those that do not.

Pesticides

Pesticide uses in IPM are generally based upon information generated by some form of monitoring. As IPM programs have become more widely adopted, there has been a trend away from using residual, broad spectrum materials toward those that are intrinsically selective. An exception in the United States has been a trend toward increased use of residual, broad spectrum herbicides. Certain conventional pesticides are being used with specificity to some degree. Low dosages of the pesticide are applied in a manner which does not interfere with the activities of the natural enemies of the pests.

Current research on insecticide development is focused on chemicals to regulate insect growth such as juvenile and molting hormone mimics, on microbial insecticides, and on pheromones. Successful microbial insecticides, such as *Bacillus thuringiensis* and the codling moth granulosis virus, and pheromones used as mating disruptants must undergo a registration process similar to that for pesticides. Their specificity and the registration process have been factors in limiting the number of these materials commercially available.

Biological Controls

There are a number of approaches in using biological control agents. Conservation and enhancement utilize natural enemies that are already present in the crop system. Conservation is the avoidance of measures that destroy biological control agents, while enhancement is the use of measures that increase the longevity or abundance of natural enemies. Classical biological control—the importation and colonization of biological control agents—is used to combat pests which have become stablished in a new area in the absence of the agents. Augmentation—the propagation of large numbers of biological control agents for release against specific pests at strategic times—is a third approach.

Cultural Controls

Cultural controls are modifications of the physical environment that reduce the survival or reproductive capacity of pests or their ability to attack crop plants. Common procedures include adjustment of tillage methods, restricted planting and harvest dates, and irrigation. Other approaches include the use of trap crops, cover crops, and mulches; crop rotations; crop residue destruction; removal of alternate hosts; and pest-free seed or transplanting stock.

Host Plant Resistance

Development of varieties which possess genetic defenses that reduce the susceptibility of plants to pests has led to one of the most widely used and most successful of all pest control tactics. Resistance can be ecological, physiological, or physical. Ecological resistance results from asynchronies between host plant and pest development. Tolerance—the ability of a plant to sustain relatively high levels of pest infestation without suffering damage or yield loss—and antibiosis—the suppression of a pest by reducing its vigor or developmental rate—are forms of physiological resistance. Nonpreference occurs when a pest is either repelled or not attracted to a host plant.

Genetic Controls

The sterile male technique is the most successfully applied genetic control for insects. Researchers continue their attempt to use genetically-altered races of pests for autocidal control.

SYSTEMS APPLICATIONS

It is not possible to fully understand the complexity of interactions both within and between the crop, the pest complex, the natural enemy complex, and the environment. Thus, one area of integrated pest management research that has become increasingly important is the development of systems which attempt to define the development and interactions of various parts of the agro-ecosystem in mathematical terms. Phenological models discussed earlier are examples of simple attempts to explain the physiological development of certain organisms in terms of a single factor: their exposure to the environment. Despite their simplicity, such models are being widely used for timing control actions and monitoring activities of pests for which they have been developed.

Physiological models and multitrophic level models are more complex than phenological models and are intended to predict population abundance, and often crop loss, in addition to timing. Such models have proven useful to researchers in clarifying the interactive processes within the agro-ecosystem. They have also been used to develop economic threshold levels for various pests under a variety of conditions which would be difficult to duplicate in field research, and they can be helpful in identifying relevant areas of future research.

Management models can assist in determining optimal management strategies in field conditions specified through monitoring activities. Such models can be complex or simple depending upon the level of complexity required to project the event with a given level of accuracy. Expert systems represent a new area of research which holds promise for future management applications.

IPM RESEARCH PROGRAMS IN THE UNITED STATES

IPM research activities are conducted at the national, state, and local levels. On the national level, the U.S. Department of Agriculture (USDA), EPA, and the National Science Foundation (NSF) provide major funding for IPM research. These agencies combined to fund the Huffaker Project (1972-1979) and later the Consortium for Integrated Pest Management (1979-1984) which focused on management systems for several major crops. The Agricultural Experiment Stations and the Cooperative Extension Services of the Land Grant colleges and universities continue to fund IPM research on a number of crops and environmental resources.

The University of California received funding from the California State Legislature in 1979 for a special project to develop and implement Integrated Pest Management systems on selected California commodities. This program has become a model for other interdisciplinary research programs. In addition to funding research, the University of California Statewide Integrated Pest Management Project employs a group of technical writers who have produced a series of IPM manuals. In addition, six Cooperative Extension IPM advisors have regional assignments. Finally, a computer staff developed and now maintains an IMPACT computer system which consists of large data bases of weather information and pest management guidelines as well as useful programs for management and research.

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Integrated Pest Management in Czechoslovakia and its Perspectives

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Plant protection has undergone a substantial change within one generation. This is due to intensification of agriculture, to new technologies, to environmental changes, and to changes in our lifestyle.

The extensive practice of repeated use of pesticides has ruined the already simplified, often degraded agrobiocoenoses and adjacent biocoenoses, and in many cases has improved the life conditions of specialized pests. Most insect pests have developed resistance, and the spectrum of pests has changed. Residues of pesticides are increasing and, consequently, so are health hazards to humans and the environment.

Methods of plant protection have been changing accordingly, with an emphasis on biological and ecological approaches. The strategy of a comprehensive approach using a wide range of methods is gradually being recognized as a much more effective form of plant protection than traditional practices, and this approach offers very good prospects. We are beginning to understand that plant protection is not a simple matter of intensification, but can be a stabilizing factor for harvests with harvest size determined by a complex of ecological and related circumstances. This principle can be applied through integrated protection of plants.

The first attempts at integrated plant pest control in Czechoslovakia were undertaken 30 years ago, at a time when chemical methods seemed to represent the ultimate solution in pest control (Rosický, Weiser 1951). The staff members of the newly founded Institute of

Entomology of the Czechoslovak Academy of Sciences (CSAV) gathered new information on general and applied entomology in order to have a solid basis for the development of new and more effective methods of controlling insect populations detrimental to agricultural production and forestry, taking into account possible effects on the environment (V. Landa et al. 1956,1958, Skuhravý et al. 1983, Kalina et al. 1985). They studied the hormonal regulation of insect ontogeny and reproduction (Slama et al. 1974); intraspecies system of communication, population dynamics, and relationships of entomocoenoses (Skuhravý, Novák 1957, Skuhravý et al. 1957); resistance to insecticides (Hrdý et al. 1968); pathogens of insect pests (Weiser 1966); parasites and predators (Starý 1970, Hodek 1973); and insect ecology. The results have been applied to integrated plant protection (Hrdý, Hrdličková 1981).

Using these results, the Institute developed several biologically active compounds (juvenoids, sterilants), biorational means of pest management (pheromones), and microbiological preparations (Baturin, Boverol). These products have been developed in collaboration with other Czechoslovak institutes, particularly the CSAV Institute of Organic Chemistry and Biochemistry. Methods were also developed for the mass rearing of parasites and predators (Havelka 1978), as well as for monitoring of and selective protection from various species of phytophagous insects and mites on apple orchards, hops, and greenhouse vegetables. Questions concerning the effects of biologically active compunds on insect reproduction have been studied extenseively at the Institute of Entomology. The results have been used as a basis for the study of chemosterilants and sterilization (V. Landa et al. 1965,1969,1971).

The Institute of Experimental Phytopathology and Entomology of the Slovak Academy of Sciences (SAV) Center for Biological and Ecological Sciences specializes in the study of phytopathogenic and phytophagous organisms and the relationships among them (Weismann 1962), host organisms and the environment (Blahutiak 1982), and the autecological, demecological, and synecological aspects of virus and fungus diseases of insect pests, their parasites, and their predators (Weismann, Huba 1966). Similar ecological studies have been conducted in the CSAV Research Institute of Plant Protection at Praha-Ruzyně and in the Plant Protection Departments of the Faculties of Agriculture in Prague, České Budějovice, Brno, and Nitra. Together, these studies provide the information necessary for determining ecological thresholds and for recognizing the circumstances under which these thresholds may be exceeded. Methods of long-term and short-term forecasting and monitoring have been elaborated, and the ecological foundations of integrated plant protection have been established (Huba 1972,1973, Kralovič et al. 1975).

Studies of defensive responses and resistance of plants to fungal diseases and of the mechanisms of interaction between the virulence genes of phytopathogenic fungi and resistance genes of host plants contribute to the application of genetic methods of protection. Such studies are conducted in the SAV Center for Biological and Ecological Sciences and in the Research Institute of Plant Protection at Praha-Ruzyně. Methods of meristematic tissue and embryonic cultivation developed in the CSAV Institute of Experimental Botany and in government research institutes enable us to obtain healthy, virus-free seedlings, and are already used for biological protection of plants against viral diseases (Novák 1987).

Agrotechnical methods of plant protection now receive more attention in several specialized institutes and plant production departments of the Agricultural Universities. The object of this research is to create ecological conditions for the physiological activity of plants which enhance their resistance to pests or create conditions that retard the development of pests.

The present standard methods of integrated plant protection in Czechoslovakia do not allow us to take more rational measures in regulating the occurrence of weeds in agroecosystems. We have no institute specializing in this field. Botanical institutes of the CSAV and SAV as well as some specialized institutes for plant protection concentrate on the application of herbicides, on agrotechnical methods, on the resistance of weeds to herbicides, and on changes in the spectra of species. Unfortunately, we do not have enough ecological data on the functional relationship between weeds and crops with regard to harvest, nor do we have enough data to determine and assess economic thresholds. However, ecological studies of weeds are currently underway.

An important step in advancing regulated multicomponential plant protection was the Czechoslovak fundamental research project "Integrated Protection of Cultured Plants," which was carried out between 1981 and 1985 (Weismann 1986). Its aim was to bring existing specialized studies to the application level and to synthesize and apply their results in a program of integrated plant protection. The first phase of the project was designed to introduce regulated multilateral protection of selected crops using lower doses of pesticides. The next step was to ensure production and application of biopesticides and other biorational preparations and bioagents for plant protection. These preparations were developed in the laboratories of the CSAV, SAV, and various universities. Satisfactory results were achieved in both phases of this research.

Five bioinsecticides have resulted from the project. They were developed in the Institute of Entomology and are based on *Bacillus thuringiensis* (Vaňková, Purrini 1979; Weiser, Prasertphon 1984), *Beauveria bassiana* (Samšiňaková et al. 1981), *Verticilium lecanii* and *Aschersonia aleyrodis* (Weiser 1983). Also, biorational preparations and devices such as pheromone traps IT-Etokap, CP-Etokap, and Ferokap-EP (Zumr 1987) were jointly developed in the CSAV Institute of Organic Chemistry and Biochemistry and the CSAV Institute of Entomology. Visual insect traps were designed in the SAV Center for Biological and Ecological Sciences. Methods of mass rearing, distribution, and application of three species of predators and parasitoids were developed at the Agronomy Faculty of the Agricultural University at České Budějovice, at the CSAV Institute of Entomology, and at the SAV Center for Biological and Ecological Sciences.

Moreover, two biopreparations based on *Pseudomonas putida 11* and *Agrobacterium radiobacter* for bacterization of sugar beet and wheat seeds to prevent root diseases were developed in the CSAV Microbiological Institute and the Research Institute of Plant Production at Praha-Ruzyně. Several practical applications of the project are new methods for diagnostics and monitoring of certain pests. The first variants of integrated protection of sugar beets, wheat, alfalfa, hops, plum and apple orchards, and greenhouse vegetables have been developed at the crop level. The highest and most complete form of integrated protection has been achieved in this country with cucumbers and tomatoes in greenhouses and with sugar beets.

The method of complete protection of greenhouse crops—mainly cucumbers and tomatoes—was jointly developed and applied in practice by the CSAV Institute of Entomology, the Agronomy Faculty of the Agricultural University at České Budějovice, and the agricultural cooperative at Chelčice. It consists principally of the utilization of four biological agents: *Phytosciulus persimilis*, *Encarsia formosa*, *Aphidoletes aphidimyza*, and *Verticilium lecanii* (Khalil, Taborsky 1982, Khalil et al. 1985). They are applied according to a program which depends on the specific ecological situation. These biological agents are produced by the agricultural cooperative at Chelčice with the help of the Agronomy Faculty of the Agricultural University at České Budějovice, and they are applied by employees of the cooperative.

Greenhouse farming has been developing rapidly in Czechoslovakia. Cucumbers and tomatoes are grown on 40 hectares in Bohemia and Moravia, and one-half of this acreage was treated with biological agents in 1986. On the 20-hectare experimental area insecticides were applied only once at the beginning or not at all (Z. Landa 1984). The agricultural cooperative at Chelčice is now building large laboratories which will facilitate the use of biological methods for plant protection in greenhouses and orchards. They are also being used gradually for the protection of other crops.

The integrated protection of sugar beets is based on a study of the present state of sugar beets in Czechoslovakia which was conducted at the SAV Center for Biological and Ecological Sciences. Suitable beet-growing regions were reevaluated from the agroecological point of view, and the effects of sowing methods for crops, agricultural techniques, occurrence of weeds, chemical treatment, resistance of plants, and their physiological state and ontogeny were assessed. Also assessed were the effects of ecological factors related to human activities on the development of overabundance and on noxiousness of viruses and fungi-causing diseases of animal pests. The economic importance of the complex of diseases and pests under different ecological conditions was reevaluated and displayed on maps. Individual species were classified in three categories of occurrence: annual, occasional, and potentially harmful. The main ecological factors and their regulation were evaluated. Prognoses, economic thresholds, and methods of monitoring were also determined. Concrete instructions, together with the first variant of multicomponent protection of sugar beets, have been based on the synthesis of these data. The first variant also serves as a model for working out methods of multicomponent protection of other crops.

The following approaches are particularly important for reducing chemical use in agriculture and for obtaining the foundation for promoting the natural development of parasites and predators:

- Development of genetic methods which would enable us to keep pests under respective economic thresholds by introducing lethal genes into their populations;

- Regulation of reproduction either by reduction of insect pests through sterilization or by enhancing the reproductive capacity of predators and parasites;
- Collection of more information about weeds and herbicides, especially with regard to the ecological relations between weeds and crops to gradually reduce the use of herbicides with adverse effects;
- Utilization of the results of plant breeding for resistance, above all to fungal diseases. The effects of nonagressive strains of phytopathogens should also be studied to determine defensive responses.
- A wider use of meristem and tissue cultures in order to obtain virus-free seedlings. The production and application of monoclonal antidotes should be extended to aid the diagnostics of virus diseases.
- Pesticide research focused on specific active compounds, although this may be seen as counterproductive by manufacturers. New biologically active compounds (juvenoids, sterilants, insect growth regulators) should be used where they are suitable and where their application is preferable to conventional insecticides.

Effective and carefully handled plant protection is an important aspect of the conservation and recovery of the environment. Integrated protection is a means of ensuring this, as it includes all the prerequisites for rapid qualitative progress. It has the capacity to use existing biological methods as well as new ones based on new findings of detrimental factors, relationships within agrocoenoses, and agrotechnical methods and technologies offered by industry. New results of scientific research will be applied as widely as possible, including results from molecular biology, biotechnology, mathematical modelling, and genetics.

There are various promising lines of action which should be given support, such as:

- Searching for new microbiological preparations for application in plant protection; selection of active strains and strains with specific effects; searching for microorganisms which produce biologically active substances (metabolites) which can be the basis for new bioinsecticides, herbicides, and fungicides;
- Introduction of new predators and parasites, and enhancement of their effectiveness by selecting and improving new strains;

- Design and improvement of the models of evolving relations between parasites and predators to enable us to anticipate the development of a pest species in a specific area under specific conditions;
- Extension of the production and use of pheromones and other semiochemicals which make chemical treatment more effective. All kinds of possible interferences with insect behavioral patterns should be used for direct protection of crops.
- Improvement of our knowledge of the effects of pesticides on non-target organisms and whole biocenoses. We should lend support to the work of SGOMSEC on "Methods for Assessing Adverse Effects of Pesticides on Non-Target Organisms." A workshop on this subject will be held at Ceské Budejovice in 1988, and a volume with this title will be published in the SCOPE series.
- Improvement of technical standards for the application of pesticides in order to reduce doses of pesticides without impairing their effectiveness.

The most important task of integrated plant protection is to assert its ecological importance in relation to the environment. It is not enough to concentrate on the pest; the whole complex—including the crop, pest, structure, and development of the cultivated landscape—must be taken into account.

These are only a few examples and ideas documenting that progress in plant protection is feasible. Although agricultural production will be intensified, its detrimental impact on the environment can still be reduced. We believe that scientific resources are great in this field and that collaboration of Czechoslovak scientists with scientists in the United States could bring important results.

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Applicator Exposure to Pesticides

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In handling chemicals for laboratory, agricultural, or domestic use, there is always an element of risk. The eminent toxicologist John Doull once said, "The safest chemical in existence can be handled dangerously, and conversely the most dangerous chemical can be handled safely."

The issue of pesticide use reflects this statement. Pesticides are of great benefit in the production of foodstuffs and are widely applied. But while some very toxic insecticides are routinely applied with no adverse affects to the applicators, chronic exposure to pesticides and potential long-term health effects are always of concern. This paper discusses techniques for measuring exposure to the applicator during the agronomic use of pesticides.

Since the 1950s, scientists have been concerned about the measurement of worker exposure to pesticides. In 1962, Durham and Wolfe reviewed the methods for measurement of the exposure of workers to pesticides. In 1985, Turnbull edited the book "Occupational Hazards of Pesticide Use" which reviews the literature on the subject from 1951 to 1984.

There are two basic approaches to measure exposure. One approach is to measure the external deposition of pesticides on the worker's body. This dermal deposition approach is utilized primarily when little information on the pharmacokinetics (absorption, metabolism, and excretion) of the chemical is available. The second approach is biological monitoring for the pesticide or its metabolites in the worker's body fluids, usually urine or blood. Discussed below are the ways that these two approaches address measurement of exposure through the respiratory, dermal, and oral routes. Also considered are other related studies and their use in the calculation of an estimated worker body dose.

PASSIVE DOSIMETRY STUDIES

Dermal absorption is the major route of pesticide exposure during the agricultural application sequence. Dermal exposure is usually estimated by the "patch technique" originated by Durham and Wolfe which involves attaching 10 to 12 absorbent pads at various locations on the worker's body. Patch techniques typically measure deposition on a small 100 square centimeter gauze pad, and the amount of pesticide deposited on the pad is multiplied by an appropriate factor to represent the larger skin surface area where it was affixed. These pads tend to overestimate exposure by trapping some liquid which undoubtedly would be displaced from the skin surface during physical activity. In addition, actual pesticide deposition is highly variable and estimates depend upon whether splashes hit or miss the pad. If a splash or a few droplets hit the pad, then the extrapolation to the whole area—which amounts to as much as 35.5x—could be significantly overestimated. Conversely, if a splash or droplets miss the pad, the extrapolation could be underestimated. Thus, this dermal deposition technique requires many replicates to provide reliable estimates of exposure.

An alternative approach to measuring dermal deposition is the disposable coverall. Some researchers have removed the coverall garment and sectioned it into parts such as the legs, above and below the knee; the arms, above and below the elbow; and the front and back of the torso. A patch still needs to be used on the head. Contamination in the removal and sectioning process is a concern, and the analyses of these large sized samples cause numerous analytical problems.

To assess the protective value of clothing, some patches are placed inside the clothing and compared to patches placed in adjacent areas outside the clothing. Protection factors estimated in this manner are highly variable depending upon the type of clothing worn, resulting in order-of-magnitude differences in similar studies.

Pesticide exposure to the forearms and hands account for approximately 70-90 percent or more of total dermal exposure. Hand contamination has been estimated from analysis of hand rinses and of thin cotton absorbent gloves worn during an operation. A criticism of the hand rinse technique has been that it only removes the unabsorbed residue of the deposition and may underestimate exposure. On the other hand, cotton gloves have been criticized for overestimating exposure due to absorption of more liquid than would normally adhere to the skin.

Many studies have shown that most of the dermal exposure occurs to the hands in mixing, loading, or tank-filling operations. Rubber gloves are used to prevent hand exposure, and numerous studies have been aimed at determining glove protection factors. Also, glove material studies have been performed with diffusion cell apparatus to investigate which materials provide the most resistance to penetration. The results show that most rubber glove materials are adequate for the duration of worker exposure to pesticides. Indeed, most exposure to the hands results not from penetration but from the glove removal process. Data to support this contention stem from analyses of cotton gloves worn under rubber gloves. Significantly higher exposures have been shown on one hand as one rubber glove is removed with a rubber gloved hand and the other rubber glove is removed with a bare (cotton gloved) hand. Thus, the U.S. Environmental Protection Agency (EPA) is recommending that the rubber gloves worn during pesticide use be rinsed with water before removal.

Inhalation exposure estimates have been made in passive dosimetry studies by analyzing filter pads attached to respirators worn by workers. However, there are major disadvantages in monitoring respiratory exposure by pads: the pads themselves may not be an efficient trapping medium for the pesticide studied; the pads are easily contaminated by the worker's hands; and the pads often become very wet due to exhaled moisture which could lead to hydrolysis of some chemicals. A preferred alternative approach has been the measurement of the airborne concentration of the pesticide in the breathing zone of the worker. The concentration is then multiplied by an estimated respiratory rate. This has been accomplished through the use of air sampling pumps which draw a known volume of air through a collecting material that traps the pesticide. Personal air-sampling pumps have been found to be most convenient for this sampling. The sampling media usually have been absorbents such as silica gel, activated charcoal, florisil, alumina, and polyurethane foam plugs.

When the inhalation exposure is calculated with analytical data from the trapping media, 100 percent human absorption is assumed. Oral exposure, whether by ingestion of air particulate or dermally contaminated food, is not accounted for in the passive dosimetry studies.

In the case of dermal exposure, 100 percent human absorption is assumed unless additional studies have shown otherwise. *In vivo* animal dermal penetration studies have been used by some researchers for this purpose. The hair of the back or abdomen skin of the test animal is lightly shaved to permit efficient application of the pesticide to the skin. The pesticide is applied and after an interval washed from the skin surface. Accountability is achieved by adding the amount of pesticide residue excreted in the urine and feces to the amount washed from the skin. Total accountability is often poor with these studies, so the amount of pesticide which is not accounted for is added to the amount absorbed for a conservative estimate.

Some researchers have used *in vitro* human skin studies as an alternative to estimate the amount of percutaneous absorption. Since absorption through the membrane barrier (*stratum corneum*) of the skin is presumed to be a passive diffusion process, no elaborate conditions to maintain the physiological state are required. Freshly obtained abdomen skin is used in a two-chambered diffusion cell apparatus where similar fluid is placed on both sides of a membrane, and the diffusion of a compound from one side to the other is observed. A more representative apparatus developed by Franz has a one-chambered cell with the *stratum corneum* surface of the skin exposed to the environment. The receptor fluid is continually circulated and maintained at a physiological temperature. The *in vitro* technique also suffers from a lack of total accountability of the pesticide due to such physical parameters as volatility, solubility, and skin uniformity.

In general, comparisons of *in vivo* and *in vitro* techniques have shown poor correlations. It is known that considerable variation in dermal absorption is a result of inconsistent penetration through skin at various anatomical sites. For instance, according to Maibach the penetration rate for foot (plantar) skin is approximately 300-fold less than for scrotum skin, and the rate for back skin is one-half that for palm skin. These studies provide the final piece of information that allows the calculation of the absorbed percentage of deposited pesticide which, when added to the inhalation exposure, estimates the total body dose.

To assure the quality of the data resulting from a passive dosimetry study, several measurement parameters should be included. Control samples should be exposed for the expected test interval to the ambient environment at the test site prior to the operations. When analyzed, these control samples provide an ambient background level. Other control samples should also be fortified with the pesticide at expected levels and handled, transported, and stored in the same manner as the study samples. These fortified samples can then be analyzed simultaneously with the study samples to provide a correction for transport and storage stability as well as for analytical recovery.

There are several advantages to a passive dosimetry approach. The chemical analysis of the parent active ingredient of the pesticide is relatively simple. The tests are completed after the operation, and there is no need to continue monitoring the worker. Each operation such as tank mixing and loading or application can be tested individually even if performed by the same worker. Finally, the pharmacokinetics of the pesticide need not be known.

BIOLOGICAL MONITORING STUDIES

Some biological monitoring studies have measured specific effects of acute exposure such as the organophosphorus depression of cholinesterase. In these studies blood samples for cholinesterase are collected by standard venipuncture techniques. The most recent biological monitoring studies consist of measuring urinary pesticide and metabolite levels.

Biological monitoring by chemical analysis of the worker's urine, in contrast to passive dosimetry on the worker or ambient monitoring of the environment, directly evaluates the amount of chemical that is absorbed by the body as an internal dose. Biological monitoring takes into account many factors which have to be estimated in tangential studies or assumed when approached by the passive dosimetry technique. For instance, biological monitoring automatically accounts for inhalation, oral exposure, clothing protection, and percutaneous absorption. However, sufficient metabolic and pharmacokinetic data are a prerequisite for providing a quantitative measure of body dose.

The optimal preparation for a biological monitoring study is a human pharmacokinetic study when absorption, metabolism, and excretion of the pesticide are intensively studied. Most of the time, this is not a viable option because of ethical considerations. In lieu of human data, three types of animal studies can be used to demonstrate the probable pharmacokinetic behavior of the chemical under study. First, an oral 14C-radio-labeled pesticide dosing study with rodents, which provides sufficient amounts of excretion products for metabolite identification purposes, is typically required for pesticide registration. These data then serve as a basis to develop analytical methods to monitor the biological specimens for pesticide residues. The second type of study involves an intravenous (IV) injection of 14C-labeled pesticides to an animal such as the monkey, which has shown to be a good model for man. It is used to determine excretory recovery and distribution of the total amount of the chemical between urine and feces. These data are used to provide the necessary correction factors for interpreting the data developed in subsequent dermal monkey studies. The third type of study is a dermal application of 14C-labeled pesticides to monkeys, which provides percutaneous absorption data regarding the percent of residue in the monitored matrix from a dermal dose. It also confirms the IV excretion profile if enough pesticide is absorbed through the skin. These three types of studies form a good scientific basis for an accurate biological monitoring approach to applicator exposure.

To conduct a biological monitoring study, several quality control measures are necessary to insure a scientifically valid study:

- Pre-exposure biological specimens should be collected from the test subjects and analyzed to obtain a reliable baseline which enables establishment of the Limit of Detection (LOD) and the Limit of Quantitation (LOQ).
- Pre-exposure biological specimens should be fortified with the pesticide active ingredient and representative metabolites at the field site prior to the testing. These fortified controls are frozen and shipped to the laboratory along with the study samples. When analyzed simultaneously with the study samples, the fortifications are used to correct for transport, storage stability, and analytical recovery.
- Urine is the most commonly employed biological specimen for these studies. Based on pharmacokinetic studies, all urine specimens should be collected for the determined interval of excretion plus an additional baseline time period. To avoid an excessively large number of urine samples from this collection, specimens can usually be combined into 12- or 24-hour composites for analysis.
- Test subjects are requested to avoid subsequent exposure to the

pesticide during the urine sample collection period in order to maintain the integrity of the results of the test operation.

One of the disadvantages of the biological monitoring approach is that the analysis of urine or blood specimens for pesticides and metabolites is a much greater analytical challenge than the parent analysis involved in the passive dosimetry technique. The urine matrix is especially variable from individual to individual and even within an individual's profile due to dietary inconsistency. Quite often extensive cleanup procedures are needed to remove interfering components and/or chemical treatments are needed to convert many metabolites of a particular pesticide into a common chemophore.

Calculation of body dose from a biological monitoring study is achieved by multiplying the amount of chemophore quantitated in each sample by the volume of the composite specimen and totaling the composite results. Totals are then normalized for body weight of each individual and the amount of pesticide applied by the individual. They are then corrected for the amount present in the monitored matrix as determined by the pharmacokinetic studies.

Several biological monitoring studies have demonstrated that there are undetectable pesticide residues in donor specimens. Many researchers feel that body dose estimates should be reported as a range rather than an average. In the case of low exposures of toxicologically significant pesticides, it is important to obtain an estimate of body dose from an undetectable residue. There are three approaches used to estimate these undetectable residues. The first approach, and the most conservative, is to assume the detection limit value. However, this value, when multiplied by the urine volume and plotted, demonstrates an excretory pattern that quite often can be very misleading and usually correlates only with the volume of voided urine. The second approach is to assume zero for these undetectable residues, even though they are unlikely to be zero but could probably be considered insignificant. If there is a real need for close approximation of the actual body dose, then a third and perhaps more reasonable approach can be taken, whereby a typical excretion curve drawn from measurable human applicators or animal models from dermal penetration studies is applied to the undetected data with the maxima set at the lower limit of detection.

Overall, science has contributed significantly to the improvement of measurements of applicator exposure to pesticides, particularly during the past ten years. However, most attempts to compare the two approaches of passive dosimetry and biological monitoring for measuring applicator exposure have not proven fruitful. In general, most indications are that passive dosimetry tends to overestimate worker exposure while, if the pharmacokinetics of the pesticide are known, a biological monitoring approach presents the most complete picture for assessing the body dose and ultimately calculating the risk to the applicator.

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Gene Engineering and Transformation of the Plant Genome by Agrobacterium Vectors

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Newly developed methods of gene engineering permit the analysis of the plant genome structure to the level of primary sequences of nucleotides in DNA. Such an analysis leads to the understanding of gene structure and the regulation of individual genes and gene batteries. An important part of such a complex study is the introduction of foreign genes into the plant genome. Among the several methods of introducing foreign genes, the most developed is the use of vectors derived from the Ti plasmid of *Agrobacterium tumefaciens*.

This naturally occurring soil bacterium causes tumor growth in dicotyledenous plant tissues due to the integration of a particular segment of the Ti plasmid of *A. tumefaciens* (transferred DNA or T-DNA) into the plant genome (Chilton et al. 1977). The expression of T-DNA genes—in particular those coding for new pathways of auxin synthesis and cytokinin synthesis—causes dedifferentiation of plant tissues and their unlimited growth (Willmitzer et al. 1982).

The dedifferentiating genes or oncogenes can be removed from T-DNA and replaced by other genes. These are then transferred to the plant genome, and the transformed tissues are capable of normal, undisturbed differentiation and morphogenesis. Several bacterial, viral, animal, and plant genes in intact or modified chimeric form have already been introduced into and expressed in the plant genome.

In the study of the effect of T-DNA genes, coding for new pathways of biosynthesis of phytohormones provides a unique opportunity to study the effects of an endogenous increase of phytohormones on several sites of plant hormone activity. Of interest are the transcription activity of the plant genome and the regulation of specific enzymes and many types of morphogenetic activities including initiation of flowering or differentiation of tubers.

The study of the expression of introduced foreign genes other than T-DNA provides insights as to the process of regulation of individual genes. Of great importance are the practical outputs of this research, and particularly the possibility of enrichment of the plant genome by genes from unrelated organisms which can provide important properties to the cultivated plants. It is possible to construct new genomes of cultivated plants which are resistant to bacterial and fungal diseases and which provide higher yield quality, especially with regard to proteins. There are already encouraging results of the first field experiments with transformed tobacco plants, expressing the gene for delta-endotoxin from *Bacillus thuringiensis*. These plants show resistance to the moth *Manduca sexta*.

The number of cloned genes useful for improving the plant genome sharply increases, perhaps doubles each year. There is no doubt that this technology will change the concept of dicotyledonous cultivated plants for future plant breeding.

The Department of Plant Breeding Theory of the CSAV Institute of Experimental Botany is studying the effects of integration of T-DNA into the genome of different dicotyledonous plant species from three points of view:

- Introduction of the whole, unmodified T-DNA of different Ti plasmids of *A. tumefaciens* and *A. rubi* strains and integration of Ri plasmids of *A. rhizogenes*;
- Introduction of single T-DNA genes;
- Introduction of other genes.

In most plant species, the introduction of T-DNA of *A. tumefaciens* to the plant genome induces undifferentiated tumors or teratomas—clumps of modified leaves and short, thick shoots—which never form roots but often form undifferentiated tumors. We have shown that the model cruciferous plant *Arabidopsis thaliana* is exceptional from this point of view (Ondřej et al. 1984, Pavingerová et al. 1983, Pavingerová et al. 1984). Tumors derived by all *Agrobacterium* strains possess considerable ability to differentiate transformed plants and teratomas. They show the presence of T-DNA in their genomes by Southern blotting, and they possess opine synthesizing activities.

Opines are low molecular weight compounds produced by enzymes which are coded by T-DNA. Plants differentiated from *Arabidopsis thaliana* with crown gall tumors never form roots but, due to their small size, they can be grown on the agar medium to the flower and seed stage. In the next generation, plants form roots, and they do not show phenotype deviations from controls. The opine synthesis markers (octopine and agropine) segregate in most of the clones in a 3:1 ratio which demonstrates that T-DNA is present in the *Arabidopsis* genome at a single site. In the next generation of opine positive plants, however, the proportion of opine synthesizing plants was always lower than theoretically expected at a 5:1 ratio. In still the next generation, opine synthesis was shown only by a small proportion of plants, but most opine negative plants showed the presence of T-DNA by the Southern blotting test. DNA methylation was therefore suspected as the probable cause of the disappearance of opine synthesizing activity.

To test this hypothesis, a seed sample was sown on the agar medium containing different concentrations of the DNA demethylating agent 5-azacytidine. This agent caused a sharp increase of the proportion of opine synthesizing individuals. It demonstrated that the methylation of cytosine in T-DNA is the cause of deactivation of opine synthesizing genes.

The T-DNA of *A. rhizogenes* strains induces a proliferation of transformed roots (Chilton et al. 1982). These roots, like crown galls, are capable of unlimited growth on agar media without the addition of growth regulators, external auxines, or cytokinines. Roots are capable of regeneration of plants (Ondřej and Bísková 1986). We have used *A. rhizogenes* strains, adapted as binary vectors (Ondřej et al. 1986). In addition to their Ri plasmid, they also contain smaller vector plasmids, which possess T-DNA border regions necessary for the integration into the plant genome and chimeric in plant cells expressing kanamycin resistance gene (An et al. 1985). This gene was transmitted and integrated into the plant genome together with T-DNA of the plasmid Ri.

Root cultures were derived in our laboratory from several plant species: tobacco, petunia, potato, pea, and *Atropa belladonna*. All roots contained high quantities of the opines agropine and mannopine. If the small plasmid of the binary vector pGA472 was also involved, most of the root cultures were able to grow on high concentrations of kanamycine. *Atropa belladonna* and tobacco roots spontaneously formed plants. *Atropa belladonna* root cultures, which produced alkaloids, were capable of plant regeneration even after two years of *in vitro* culture (Ondřej, Protivá 1987). In petunia roots, we have shown the karyotype stability of meristems (Ondřej, Bísková 1986). Tobacco plants regenerated from roots did not show any morphological deviations.

Opine-synthesizing abilities were found in both anther calli and seedlings. Regenerated plants were studied from the point of view of the growth and photosynthetic activity. Growth was slower than in untransformed controls. Photosynthetic activity was not decreased, but the respiration rate was increased, which explains the observed growth retardation.

The third species studied—*Agrobacterium rubi*, defined on the basis of numerical taxonomy—has Ti plasmid, which is comparable in size with those of *A. tumefaciens* (about 200 kb). The behavior of so-called "cane gall tumors" induced by *A. rubi* has never been studied before. This species was believed to be specific for the genus *Rubus*; however, we have induced tumors with differentiated plants on tobacco, petunia, and potato. We have also studied the properties of the opine synthesizing enzyme lysopine dehydrogenase.

This work, with the use of full-length T-DNA, is nearly finished. At present, we are interested in vectors which do not integrate oncogens into the plant genome, but only selectable genes for kanamycin resistance together with other cloned genes. We are interested in integrating virus cDNA sequences into the plant genome, which can introduce virus disease resistance to the genomes of cultivated plants by several mechanisms:

- By transcription of anti-RNA, which is capable of forming double strands with mRNA *in vivo*. These double strands cannot be translated, and virus reproduction is thus blocked.
- By integration and expression of the coat protein gene. The coat protein has already been demonstrated to induce resistance by a mechanism related to cross-protection.
- By integration of the cDNA sequence, which codes for satellite RNA of the virus.

There is particular interest in potato viruses, viroid cDNA sequences, and in cauliflower mosaic virus. Cooperation in this field with scientists from the United States would be welcome.

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Development of Genetic Resistance to Disease and Pests and its Implementation in Industry

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Since 1905—when R.H. Biffen first reported on the heritability of striped rust disease resistance in wheat—plant breeders have been attempting to improve yield and reduce dependency on chemical methods to control diseases by breeding disease-resistant genes into crops (4). While success has been achieved in some crops for certain diseases, the potential envisioned by researchers in the first half of this century still has not been realized.

In general, where disease resistance has been found within the species and has behaved as a single Mendelian trait, plant breeders have bred the resistance into commercial crop cultivars. Where the resistance has not been controlled by a single gene, this process has usually been difficult for diploid crops that are bred intensively to produce many new cultivars. Conversely, where single gene resistance has been in commercial use for 20 to 30 years, resistant strains of fungi have developed as predicted by plant pathologists, such as in resistance to *Verticillium* and *Fusarium* species. With a few exceptions, insect- and pest-resistant cultivars have not made a significant impact on commercial crops of the food processing industry. The complexity of breeding resistance to insects, mites, nematodes, and other pests into food crops has been very great. Although levels of resistance have been found in various crops, breeding problems have limited development. For example, resistance to nine different species of insects has been reported within the tomato genus, yet none have been commercialized (8).

While farmers, food processors, and the fresh market produce industry have generally embraced disease-resistant cultivars, there are a number of exceptions which reveal the historical priorities of the agricultural industry. In one sense, the industry is driven by the consumer, with the quality and value of the finished food product determining whether disease-resistant cultivars will be implemented by the industry. In reality, however, the food processor's perception of the consumer's desire for quality and value determines the implementation decision.

The form in which disease resistance is presented to the industry is very important. The genetic resistance comes in at least three forms of readiness to use: new cultivars, inbreds, and germplasm. The tomato industry offers us an opportunity to review the results of substantial efforts to breed disease resistance into a popular food crop; in 1952, nearly every U.S. state had an active tomato breeding project to search for resistance to at least one disease (9).

NEW DISEASE-RESISTANT CULTIVARS

Historically, plant breeding in the United States was a public service and a responsibility of land grant universities and the U.S. Department of Agriculture (USDA). Today some new crop cultivars are developed by universities and USDA, but more are developed by private industry. In all cases, a need perceived by the industry is a prerequisite for the commercial introduction of a new cultivar.

Working through crop science and food science departments, university extension services perform a valuable function by focusing university researchers on industrial problems and on areas for potential improvement. University/industry committees review university research results and develop financial support for research projects. The tomato breeding program at the University of California is an example of industry-supported research that has been very beneficial for farmers and the food processing industry. Such cultivars as VF145-7879, VF134, UC82, and UC204 have been widely used in California and all over the world.

The Food Science Department of the University of California at Davis has helped industry considerably by evaluating new cultivars for product yields. Whenever a cultivar is improved for disease resistance, it must be tested for standard product yields. These results are adopted by industry on a needs basis, again drawing on the communication efforts of the extension service.

The extension service has also played a role in evaluation of products from private industry. In addition to new cultivar evaluation, the extension service is continually testing new fertilizers, irrigation methods and products, herbicides, pesticides, and seed treatments that, along with new disease-resistant cultivars, lead to an improved agricultural system.

In the past, support of private industry for farmers and food processors was limited mainly to seed companies. For the past seven years, however, new research and development companies have emerged as developers or modifiers of cultivars either directly for food processing companies or for traditional seed companies. These new companies propose to bring biotechnology or molecular biology to the traditional process of breeding improved crop cultivars. This type of research is generally considered proprietary, done on a contractual basis with the objective of giving the companies involved a competitive advantage in the marketplace. Exclusive rights agreements or profit-sharing agreements are usually established between the concerned parties.

Varieties developed through this process are tested privately, not through the university agricultural extension systems. Examples reported to date are celery and carrot cultivars developed by DNA Plant Technology for the Kraft Company and a high-solid tomato cultivar also developed by DNA Plant Technology for the Campbell Soup Company. Other projects in progress are herbicide, disease, and insect resistance activities of Monsanto, Calgene, and other genetic engineering companies.

However, traditional seed companies still are the primary source of improved cultivars for disease resistance and improved quality features. Their products are tested in the university agricultural extension system for the benefit of farmers and food processors.

Private internal research is conducted by some food companies for their own needs. In the larger food companies, this type of research is dispersed through the entire vertical chain from seed cultivars of crops to retail product development, including recipes and manufacturing processes. In order to assemble a critical research mass, many companies perform research within central corporate units and then must convince their field operation units on the merits of their research. The probability of success for internal company disease-resistance development is much the same as that for research by the universities or private research and development companies, except for knowledge of the food product and process for which the crop is destined.

Most of the major food processing companies in the United States, such as Del Monte, Pillsbury, Campbell, and Heinz, have successfully developed their own disease-resistant cultivars to meet some of their product needs. For example, resistance of tomatoes to Bacterial Canker disease (*Corynebacterium michiganense*) has been developed proprietarily by the Heinz Company in response to a serious need in a limited but growing area of the company. This research is expected to provide a strong competitive advantage to Heinz in that procurement area. In addition, Basic Foods Company uniquely combined very high solids with pink root resistance (*Pyrenchaeta terrestris*) in their proprietary hybrids for the onion dehydration industry.

INBREDS AND BREEDING LINES

Universities and USDA are unique suppliers to the agricultural industry of such semi-finished products as inbred lines for hybrid use and breeding lines possessing disease resistance or other improved qualities, but require further selection or backcrossing to make a finished cultivar. This approach has a multiplier effect on the original research by allowing the line to be used by different seed companies to produce hybrids designed for different products and for different growing areas.

The current situation in regard to nematode resistance in tomatoes illustrates the value of this approach. In contrast to the very limited availability of nematode-resistant cultivars for the processing tomato industry, the fresh market tomato industry now has 50 percent of its cultivars resistant to nematodes (2).

The first of the current major fresh market cultivars was introduced in 1973 by Ferry Morse Seed Company. In this instance, the need was certainly no greater than for processing tomatoes (6). The same nematicide—DBCP (1,2-Dibromo-3-chloropropane)—was used by fresh market tomato growers and processing tomato growers. The difference was a program at the University of California, Davis, that developed suitable nematode-resistant inbreds for the fresh market industry which had accepted hybrids and was able to use the university inbreds.

Although the need was not great, the university lines could be used by a seed company to create a unique proprietary hybrid and thus offer a slight cost savings to the farmer. The nematode-resistant hybrids reduced the growers' production costs and enhanced safety for applicators by eliminating the nematicide chemical.

With the shift to utilization of hybrids even in the processing industry and the opportunity for universities and USDA to become more involved with biotechnology, the job of developing finished cultivars and hybrids is increasingly moving to private industry. Consequently, all university programs are releasing more breeding lines. In the California tomato processing industry, the seven major cultivars currently in use are all derived from breeding lines at the University of California, Davis. Many of them carry the resistance to *Fusarium oxysporum* Race 2 from the university lines.

GERMPLASM

The providers of germplasm to industry are land grant universities and USDA, particularly USDA plant introduction stations that screen new germplasm received from explorations. Although research results in this area are clear, industry has not been successful in transferring the research into practice. In addition to establishing need, industry must be able to utilize new methods. Indeed, there are numerous cases where industry and private agencies have not taken advantage of improved disease resistance.

Nematode resistance in tomatoes again provides an interesting case history for germplasm research. This pest is a major problem for tomatoes and many other crops in areas where the soil does not freeze during winter, and was first identified in 1855 in England. As reported by Bailey at the Tennessee Agricultural Experiment Station, genetic resistance was found in 1941 in a wild relative of the tomato *Lycopersicon peruviannum* var. *dentatum* (3). Sexual crossing with the commercial tomato *L. esculentum* was difficult as it required embryo culture techniques, but was nonetheless achieved in 1943 by Smith at the University of California (7). This work eventually resulted in the release of commercial cultivars in the early 1960s. However, wide-scale commercial use of processing tomato cultivars with nematode resistance has begun only recently. There have been occasional cultivars developed and released in the interim but they have not been not adapted to industry.

Why did it take more than 20 years for industry to use this research? The need was not there, as perceived by the industry. DBCP was available, having been introduced as a soil nematicide in

California in the late 1950s. It was an inexpensive ($10–$15/acre) farm chemical that gave excellent control of nematodes and could be applied in irrigation water or by tractor-mounted shank injection equipment. From 1960 until 1977 when use of DBCP was banned, about 3,000,000 pounds were used each year on California farms at a rate of 20–80 pounds per acre. It was a fine chemical, persistent, highly nematicidal, was able to spread through a soil profile, and had low phytotoxicity. It could be used on 21 crops in addition to tomatoes, including cotton, grapes, and orchard fruit and nuts. When DBCP usage was banned as a potential carcinogen, the annual cost impact to farmers was estimated to be $7,700,000 per year.

Genetic resistance to Bacterial Speck (*Pseudomonas syringae* pv. *tomato*) has also been underutilized by industry. The resistance occurs in a single dominant gene and the screening methodology is simple and economical, yet it is not being bred into cultivars with any sense of urgency by the seed industry. In this case, providing resistance to this single disease would not eliminate spraying of chemicals to control Bacterial Spot (*Xanthomonas campestris* pv. *vesicatoria*). While the disease is widespread and common in the Midwest, it is not a serious economic threat to most growers. Similarly, lack of need has deterred introduction of the newly discovered resistance to Lepidoptora species using the "Bt" gene in tomatoes. The farmer will still have to use the same insecticide for other insects.

C.F. Andrus understood the absence of perceived need in his review of tomato disease resistance in 1953 (1). He described it as follows:

> (T)he breeder striving to produce disease-resistant varieties for benefit of farmers must have a proper perspective of the entire list of diseases that may seriously damage the crop in a given area, and he would be well advised to strive for combinations of resistances that permit elimination of expenditures by classes of control measures.

Young, enthusiastic plant pathologists and plant breeders have often found it strange that farmers are seldom interested in a new cultivar because of its disease resistance. Again, Andrus concluded after 20 years of breeding experience that if a new disease-resistant cultivar is to be acceptable to farmers, it must be as beneficial as the old susceptible cultivar in all features that influence the net value of the crop, even when the disease is absent.

A prime example of this conclusion is the sweet corn hybrid, Jubilee. Developed in the early 1950s and susceptible to all diseases, it continues to be the single major cultivar for the freezing process.

Many cultivars are available now with resistance to as many as five diseases, but none has the freezing quality of Jubilee.

Along with the evaluation of need, the method of breeding a given disease resistance will often make the difference in its utilization. In the case of the tomato nematode resistance described earlier, the selection methods prior to 1975 required maintenance of the pest in infested soil. Also, field screening, with the inherent problems of potential contamination of nematode-free soils in greenhouses and research plots and problems in growing non-resistant lines in infested fields, constituted a very difficult screening method. In 1974, Rick and Fobes published a new method employing electrophoresis in a laboratory to detect a gene product (acid phosphatase) which is tightly linked to the Mi gene for nematode resistance (5). The acid phosphatase test is conducted on leaf extract and clearly detects homozygous and heterozygous resistant genotypes.

A survey of U.S. seed companies in 1975 found none with a program to breed nematode resistance in tomatoes. The original screening technique devised in 1974 has been greatly improved for cost and efficiency, and breeding for nematode resistance is now a top activity in all seed companies. The processing industry expects to have five percent of its tomato acreage in 1987 planted with nematode-resistant varieties, eliminating both the grower's cost of nematicide use and the environmental impact of such use.

CONCLUSION

In summary, the task of introducing disease-resistant crop cultivars to the food industry has proven to be complicated and difficult. The benefits should be reduction of farmers costs and reduction of environmental contamination by reducing the need for chemical control. In practice, the disease-resistant cultivar must be equally as good as the susceptible one it replaces in terms of field yield, processed product yield, and quality under all growing conditions, or it generally will not be adopted (barring severe epidemic losses with standard cultivars). Closer contacts between cultivar-developing organizations and the food industry have helped improve the development/implementation problem.

The release of disease-resistant breeding lines by universities and USDA to seed companies and other sectors of private industry provides a multiplier effect to the value of their fundamental research.

The seed companies must customize the disease resistance into a finished cultivar that is equal to or better than the present cultivar.

For the safety of the environment, public agencies must look past inexpensive chemical control measures and push ahead with breeding line development where good genetic disease resistance can be found. The chemical control class approach, advocated by Andrus, must be used to overcome the economic barrier to introduction of disease-resistant cultivars.

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Parasites of Domestic Animals and their Life Cycles in Ecosystems Influenced by Man

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Historical writings of ancient civilizations indicate that man has suffered from parasites practically since his origin. Malaria decimated the troops of ancient Rome, and microscopic blood parasites determined the results of more battles than did the most famous leaders. Fleas which transmitted a causative agent of the plague *Pasteurella pestis* caused the extinction of one-third of the European population in the 17th century. Also, populations in the tropics have been decimated by malaria, sleeping sickness, yellow fever, and schistosomiasis.

Parasites and their hosts are members of the biocenosis of certain ecosystems. Therefore, a complex ecological approach is necessary to adequately study this problem.

Since man shares the same environment with other animal species, the circulation of parasites between man and animals is quite common. For example, in Czechoslovakia the protozoan *Toxoplasma gondii* is widely distributed both in domestic and wild animals and in man. Similarly, larvae of *Toxocara canis*, a dog parasite, are often found in man as so-called *Larva migrans* (Šebek et al. 1975, Prokopič and Klabonová 1979). Many human parasites develop in domestic or wild animals, e.g., *Diphyllobothrium latum* in crustaceans and fishes, *Taenia saginata* in cattle, *Taenia solium* in pigs, and *Echinococcus granulosus* in dogs and other carnivores. *Trichinella spiralis* occurs as a parasite in all mammal species including man (Prokopić 1959,1962). Thus, rapid ecological development stimulated by the social necessity to solve basic questions concerning the environment of man and agriculture requires a complex approach.

Recent worldwide developments in parasitology have created great interest in developing countries where parasitoses of man and animals have reached large dimensions. Developments in transportation and the frequent migration of inhabitants and animals between countries and between continents influence the distribution of parasitoses (Prokopič 1983). Parasites can be easily transmitted long distances. Some species of parasites are introduced into remote places, where they have never occurred before. For example, the large liver fluke *Fascioloides magna*, which infests deers and other ruminants, was introduced into Czechoslovakia from Canada and has already spread throughout Europe. Similarly, a great number of parasitic species were introduced with the muskrat, e.g., *Ondatra zibethica*, into Europe and Asia where they have adapted to other rodents (Spassky et al. 1951). Many fish parasites have been introduced along with fish imports in recent years.

Another factor of global importance is the change of ecological conditions under the influence of anthropogenic agents. This results in new characteristics in the circulation of some parasites (Prokopič 1976). Of concern are the large-scale breeding of farm animals, intensive fish breeding, game parks, and refuse dumps. Also, some negative factors influence the life cycles of parasites so they have no possibility to realize their developmental stages in the given environment. For example, trichinellosis in pigs and man can be eliminated in large-scale breeding of pigs, since pigs have no contacts with free-living animals and the reservoirs of trichinelles in the human food chain are consequently reduced. Favorable conditions for mass occurrence of some parasites can also appear, especially pinworms and lice in children and coccidia in calves, pigs, rabbits, and poultry.

Consequently, parasitological research must be directed both to basic research and to application, especially from the point of view of prevention, chemotherapy, disinfection, and total control of parasitoses and diseases of man and animals transmitted by parasites. Application of new methods and improvement of technical equipment enable us to study thoroughly the systematics, taxonomy, and morphology of parasites.

The bionomy of individual groups of parasites, especially economically important species, must be studied intensively. Of interest in basic research of parasites are new methodologies and new technical possibilities in morphology, pathological ultrastructure, biochemistry, biophysics, and mathematics which permit more accurate elucidation of parasite/host/environment relationships. Epidemiology and epizootiology of parasitic diseases of both man and animals should be thoroughly studied.

Recently, the influence of anthropogenic factors on the development of parasites—warming of water, new technologies in breeding of farm animals, and changes in landscape—have become of great interest. We suppose that anthropogenic factors can considerably influence flora and fauna and consequently form new ecological conditions for the development of parasites. Research on parasites of free-living animals (Prokopič 1972, 1973) and parasite/host relationships in various ecosystems should not be neglected.

Numerous discoveries have been achieved in immunological research of parasitoses which have resulted in reevaluation of some concepts concerning this biological process. This trend is evident in the development of immunodiagnostics, immunopathology, and immunoprophylaxis (Kudrna, Prokopič 1985). Knowledge and application of transplantation immunology and oncology can be used in this research (Kudrna, Prokopič 1986). The acquisition of defined purified antigens for serological tests can be helpful. The introduction of biotechnological methods in production of monoclonal antibodies would be of great significance, and these antibodies could become a source of immunosorbents for obtaining highly specified antigens.

After the Second World War insecticides based on chlorohydrocarbons, especially DDT and HCH, were extensively used to destroy insect pests affecting plant production and parasites detrimental to health. Serious disadvantages of these chlorohydrocarbons appeared relatively soon, including their accumulation in the tissues of vertebrates, their toxicity, and the development of resistance in arthropods, in animal communities, and in biocenoses in general.

Studies of the relationships between hosts and parasites show the complexity and heterogeneity of problems and distinct differences in pathogenicity. Parasites have different developmental cycles which depend on specific intermediate hosts or vectors. This results in variability of responses in host tissue. In addition, parasites which develop only in one host challenge very different pathological reactions during their development (Schramlová and Blažek 1984). Protozoa attack cells directly or are destroyed by phagocytes in a multicellular reaction. A toxic effect of the metabolic products of numerous parasites has been demonstrated. This effect results in necroses of different ranges, an inflammatory response, an exudation of eosinophils, and in many cases the formation of granulome.

The present level of parasitological research in Czechoslovakia is characterized by the completion of basic faunistic research, by elaboration of bionomics of the more important parasitic species, and by determination of their role as pathoergots or vectors of causative agents. A significant advance in parasitological research in Czechoslovakia has been the acquisition of knowledge of the ultrastructure and morphology of important species of protozoa, worms, and arthropods. Much knowledge has been obtained about the geographical distribution and ecological conditions during the development of various parasitic species, including the introduction of some parasites in Czechoslovakia. Recently in the spotlight are questions of the influence of anthropogenic factors on the development of parasites, including the introduction of parasites, warming of water, new technologies in breeding of domestic animals, and landscape changes.

Special ecosystems are created by refuse dumps. Anthropogenic influences are reflected in changes in the composition of parasites and in some features of their bionomy. These changes can be so important that parasitoses which are not currently dangerous in Czechoslovakia can gradually become quite serious.

The modern age is characterized by close economic and cultural cooperation with developing countries. This provides a stimulus for intensive study of the tropics and subtropics.

Waste industrial heat creates conditions for the occurrence of parasitoses introduced from warm regions, e.g., colonies of *Monomorium pharaonis* (Kohn and Vlček 1982) and the occurrence of soft ticks *Argasidae* in dumps. Further, the existence of pathogenic amoebae of the group *Limax* has been detected in warm water and in swimming pools (Červa, Novák, and Culbertson 1968).

In advanced industrial countries, individual fields of animal production have become large-scale breeding grounds for parasites. Intensification of the production of animal products, maximum utilization of biological material, and the increase of labor productivity to provide food self-sufficiency are the aims of many countries. Large-scale breeding of farm animals—especially cattle (calves), pigs, and poultry—has resulted in many problems concerning the health of these farm animals (Kotrlá and Pavlásek 1980).

Parasites generally belong to the negative factors in breeding of farm animals; they damage the host, either directly or indirectly.

In most cases, they become "the entry gate" for other pathogenic agents. Due to high concentrations of young farm animals, optimum conditions for effects of different pathogenic agents arise.

Gastrointestinal nematodes parasitizing in domestic animals are considered to be the main cause of important economic losses. In recent years, problems of protozoan diseases of young farm animals, especially calves, piglets, and lambs have stimulated research on cryptosporidial infections.

Insecticides are still commonly used to combat parasitic insects. It is necessary to develop new, more effective, insecticides with fewer side effects and without long-term residual build up in the environment. Resistance of pests indicates a need for chemical groups which have not yet been applied, e.g., benzoylphenylurea derivatives which stop the synthesis of chitin and its accumulation in cuticula. The possibilities of utilization of chemicals which are effective on juvenoids and pheromones have not been fully explored. Some methods of biological control have good prospects, e.g., bacteria, fungi, protozoa, or nematodes (*Bacillus thuringiensis*, *Coelomomyces*, *Nosema algerae*, *Mermithidae*). Studies of genetic control are being carried out especially in *Diptera* where sterile males or females with cellular incompatibility are introduced into normal populations. Production of antibodies in hosts evoked by inoculation of tissues obtained from infesting arthropods is under consideration.

Due to the influence of anthropogenic factors, considerable ecological changes of the environment occur causing the extinction of some ecosystems and formation of new ones. Parasites react as members of ecosystems and these interrelationships warrant further study.

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Biotechnology and the Development of Microbial Products for Agriculture

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BIOTECHNOLOGY: AN ANCIENT PRACTICE AND A NEW SET OF TOOLS

Agriculture is the original biotechnology, the technical application of biological systems in the selection of plants and animals and in controlled fermentations. The "new" biotechnology rests on recent major developments in biochemistry especially related to recombinant DNA and monoclonal antibodies. Recognition at the molecular level is a fundamental characteristic of biological systems which is highly evolved in the genetic material to promote accurate replication through generations, and in the animal immune system to recognize foreign and potentially dangerous antigens. Understanding the biochemical aspects of these recognition systems has now also provided more precise tools to study cells and molecules.

Public statements create an image that this technology is being directed toward the creation of "new" organisms. Over 1,200 commercial firms are presently using recombinant and monoclonal techniques in product research and development, and the U.S. Department of Agriculture has 180 projects underway to study applications in agriculture. The genetic engineering of plants by recombinant DNA and tissue culture and advances in biomedical products from the fermentation industry can be viewed as natural outgrowths of the old biotechnology that apply the new molecular techniques. This paper addresses another equally important role for this new technology—to improve understanding of the ecology of naturally occurring microorganisms.

TABLE 1 Applications of microbial products for agriculture

Application	Types of Organisms
Silage fermentation	Lactic acid bacteria
Nitrogen fixation	Rhizobium Azospirillum, Azotobacter, Bacilli, Pseudomonas
Animal intestinal inoculants (probiotics)	Lactic acid bacteria, yeasts, Bacilli
Soil improvement, plant growth	Cyanobacteria, microalgae
Stimulators	Mycorrhizal fungi, various bacteria
Biological control - fungicides	Various fungi as parasites or predators, bacteria
Insecticides	Bacilli, viruses, fungal insect pathogens
Nematicides	*B. sphaericus*
Herbicides	Viruses, fungi
Preservation of seed	Non-toxic antagonists of fungi
Stored grain Hay	

Table 1 contains examples of microbial inoculants presently being sold or tested for agriculture. Most of them involve a fundamentally new practice of biotechnology—the domestication of microbes for use in the open environment. Beneficial uses of microbial inoculants were suggested at the turn of the century in Metchnikoff's work with lactobacilli as animal probiotics. Attempts to use rhizobium and other biofertilizers began in the early 1950s and use of insecticidal bacilli followed about ten years later. Thousands of years were previously required to domesticate plants and animals, but scientists are currently attempting to do the same with certain microbes in a single generation of directed research (8).

Microbial inoculants for agriculture have attracted the attention of researchers and companies throughout the world because they hold the promise of providing lower cost, ecologically sound alternatives to many chemical applications. The costs of chemical inputs to meet the needs described in Table 1 are rising steadily, but the value of agricultural commodities is not. Lowering the cost of inputs is recognized as an important strategy for raising the profitability of farming. If they could perform consistently and be cheaply produced, microbial inoculants would also present lower risks to animals and the environment.

The confidence of both basic and applied researchers in the future of inoculants is indicated in a recent survey of 405 biotechnology firms by the U.S. publication *Genetic Engineering News*. Over 30 percent of the firms identified agriculture as a potential market, even though only four percent had products other than animal diagnostics presently for sale or testing. These other products include cyanobacterial fertilizers, frost protectants, *Bacillus thuringiensis*- and virus-based insecticides, improved rhizobium inoculants, plant growth regulators, waste processing treatments, and fungicides.

INCONSISTENT PERFORMANCE OF INOCULANTS: THE NEED FOR AUTECOLOGICAL DATA

There are an estimated 10,000 to 20,000 strains of any given bacterial species. This represents a huge, almost untapped potential for inoculants to affect processes such as those listed in Table 1. Empirical research has shown that control of insects and plant pathogens, enhancement of nitrogen fixation, and protection of animals from enteric disease can be accomplished with selected fungi or bacteria. However, few products have given consistent results in the field. Forty years of research on microbial products for agriculture have demonstrated that not enough is known about microbial ecology of the agricultural environment to exploit it in an optimal manner.

The use of inoculants for agriculture involves their release into the environment where they compete with large and diverse indigenous populations. As is already known for *Bacillus thuringiensis* and rhizobia, they usually lose this competition. The survival and function of individual species of organisms in the natural environment are subject to many influences beyond our present understanding or control. When maintained in culture, even organisms isolated from the environment often lose qualities for which they were selected. Thus, natural conditions cannot be easily duplicated.

The study of the individual microbial species within an ecosystem is termed *autecology*. Autecological research on pathogenic organisms both in culture and the environment has been pursued because of the importance of these organisms to man and the relative ease with which they can be identified. However, the vast majority of naturally-occurring microbes are not readily identified and have been studied only as components of processes such as the nitrogen cycle. The autecology of these organisms must now be studied in order to harness their potential as inoculants (9). What are the actual numbers, functions, and fates of indigenous microbes in agroecosystems?

The current public concern over the release of genetically engineered organisms stems from a lack of the same type of information. A high priority has been placed on research in microbial autecology at this time in the United States because of the desire to monitor proposed field tests of such organisms. The U.S. Environmental Protection Agency (EPA) is currently funding 17 extramural research programs on related problems of environmental effects and on development of a methodology for estimating the fate of introduced organisms. Until now, methods for identification of specific strains of bacteria among large populations of similar strains of the same species have lacked adequate precision or have been prohibitively difficult. The large numbers and variety of natural populations also led to the concept that a physiological niche in an ecosystem was more important than the actual species which occupied the niche. Enhanced molecular recognition by the new techniques now allows researchers to reach into natural environments and locate particular organisms with a sensitivity that was not possible before. It should be possible to study gene expression specifically related to both persistence and beneficial characteristics of microbes *in situ*.

A good example of the promise and problems of microbial inoculants is competitiveness for root nodulation by rhizobium. Enhanced symbiotic nitrogen fixation by these organisms would greatly benefit agriculture (2). Understanding of the molecular biology and biochemistry of the nitrogen-fixing enzyme and the physiology of the symbiosis is far advanced after about 20 years of intensive research. However, most of this potential still has not been harnessed for crops because of the unsolved problem of determining what makes individual strains competitive for nodulation in the rhizosphere (4). Strains with superior nitrogen-fixing and nodulating capability lose out in the competition for saprophytic growth in soil or infection sites on the roots of the host. A similar problem presumably exists in the attempt to exploit associative nitrogen fixation by Azospirilla or Azotobacter for cereals.

TRACKING NATURALLY-OCCURRING STRAINS OF BACTERIA

Identification of specific strains of rhizobia for studying their ecological interactions has been a priority for years because of the desire to supplant indigenous field strains with strains selected in the laboratory. While effective at the species and serogroup level, fluorescent antibody labelling and determination of antibiotic resistance patterns lack precision for tracking strains, especially at low population densities. Some direct and much circumstantial evidence suggests that genetic exchange among rhizobia is common in soil and can change the determinants which are the basis of the assay methods. Rhizobium is also usually baited out of soil onto the host plant prior to identification. Since it apparently survives well as a soil saprophyte, a further source of inaccuracy exists. One measure of the difficulty of tracking rhizobium strains is the very large number of methods that have been published over the years.

As suggested above, identification methods that rely on first culturing the organisms have many sources of error. In an adaptation which is not yet understood, sporulated gram positive organisms as well as some gram negative organisms can enter a resting state in soil where they cannot be cultured onto laboratory media. About 100 billion bacteria per gram can be cultured from soil, while from 10 to 100 times more can be seen in samples prepared for direct microscopy. There are similar cryptic populations in other natural environments. Additionally, the colonies which do grow on agar media may not represent the cells that were physiologically most active or significant in the ecosystem sample.

An example of a new biotechnology methodology to address these problems is the current study of DNA extraction directly from soil by Drs. Holben, Chelm, and Tiedje of Michigan State University (6). Similar work is being pursued for sediment and other environmental materials.

The extraction of DNA, with the development of appropriate probes, will allow a direct measurement of the negative microbes which are actually present. Using *Bradyrhizobium japonicum* containing a recombinant gene, Holben has demonstrated the persistence of two separate strains simultaneously inoculated in natural soil by probing a restriction enzyme digest of total DNA for the recombinant sequence. Products of genetic recombination involving the gene or nearby sequences would also be easily distinguishable if they occurred in the soil. In addition, the method is simple enough to allow processing of sufficient samples to complete a well designed ecological study. This technique will permit researchers to follow not only individual strains of microorganisms but also specific genes and the fate of co-inoculated mixtures of bacteria or fungi in the natural environment. The fate of specific plasmids within the microbial population can also be determined.

THE IMPORTANCE OF PLASMIDS

Tracking plasmids in the environment is arguably more important than tracking individual strains of bacteria themselves. Plasmids are extra-chromosomal, self-replicating genetic elements by which bacterial populations maintain biochemical flexibility in adapting to their environments. Plasmid-borne functions such as antibiotic resistance or catabolism of uncommon carbon sources may be magnified as needed in a population by increasing plasmid copy number or expression. Plasmids may be lost from cells when there is no selective pressure to maintain them, and they may transfer to other cells, occasionally mobilizing parts of the chromosome or other, non-transmissable plasmids along with them. Thus, the ecology of bacteria depends fundamentally on the ecology of their plasmids (7).

Some of the traits selected as useful for agriculture in bacteria have been found to occur only—or naturally—on plasmids. These include the nitrogen-fixation enzymes, symbiotic determinants, and probably competitiveness in rhizobia; the Ti and Ri plasmids of Agrobacterium which cause disease by incorporating into plant chromosomes and have become important vectors for plant genetic engineering; and the insecticidal crystal proteins of *Bacillus thuringienesis*. Many of the bacteriocin and antibiotic factors selected in typical screening for biological control agents are probably also plasmid-associated. A recent report by Carney et al. from the University of California on metabolism of xenobiotics by pseudomonads suggests that microbes may even recombine parts of their plasmids to develop new pathways for degradation of novel waste compounds (3). The phenotypic expression and the reason for retention of most plasmids in nature are still totally unknown.

Increased understanding of plasmids in natural populations is necessary for several reasons:

- to determine when select characters are associated with them as a basis for increasing their stability in commercial inoculants;

- to control their transfer to other organisms in the environment, especially in the case of recombinant genes;
- to maintain laboratory cultures under the appropriate conditions in order to retain desired plasmid-associated characters;
- to cure or replace them in the case of strains in which this is desirable but difficult.

PLASMID PROFILING FOR ECOLOGICAL RESEARCH

At Pioneer, plasmid characterization has been used in two areas of microbial ecological research pertinent to silage inoculant and seed inoculant products. Silage is presently the world's largest fermentation industry, and it is growing in importance in every agricultural economy. Ensiling preserves more nutrients in more crops than other methods of storage, and its use is increasing in beef and dairy cattle feed. Silage is also the feed component which varies most in quality. Addition of lactic acid bacteria to improve silage fermentation has become a well-recognized practice over the last 30 years (1). There are 91 producer/distributors of over 100 different live-culture additives in the United States alone. Strains are selected on the basis of their ability to rapidly lower the pH in the ensiled crop. Ecological research on the populations of fermenting bacteria would form a rational basis for further improving these selection criteria.

Drs. Hanna and John Hill have found that the *Lactobacillus plantarum* strains important to silage fermentation often have multiple plasmids, and that these are stably maintained both in the laboratory and the natural environment (5). Therefore, plasmid profiles—or extracted plasmids separated electrophoretically by molecular weight—show characteristic patterns which identify individual strains. Strains which do not have plasmids have been identified by their biochemical profiles.

Figure 1 presents an example of plasmid profiles of *L. plantarum* strains isolated from 32-day-old uninoculated high moisture corn silage. The pH had been stable at about 4.0 for at least 3 weeks, and overall lactic acid bacteria numbers were continuing to slowly decrease from an initial peak reached in the first week. The variable banding pattern in the gel represents plasmids of different molecular weight. There are eight distinct types, indicating that at least eight strains of *L. plantarum* are present. It is also apparent that two are dominant. In Figure 2 the same analysis has been made of inoculated silage. In this case the only *L. plantarum* strains recovered were those

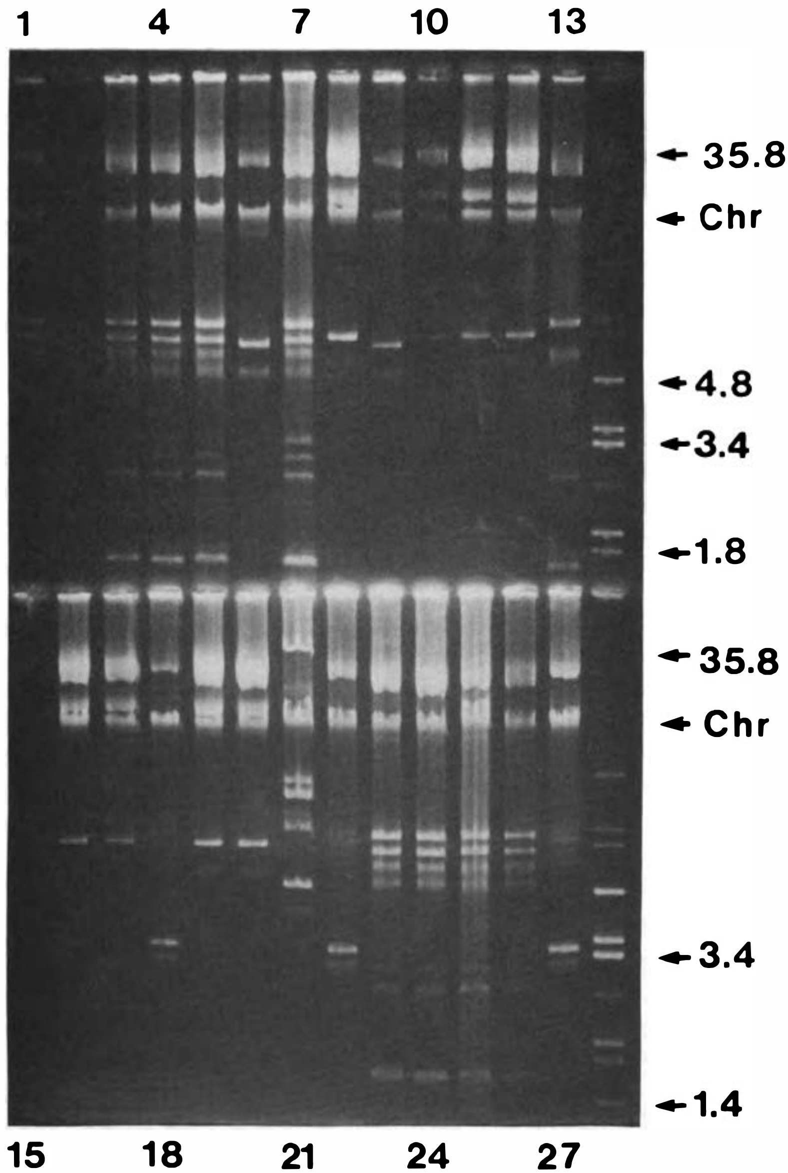

FIGURE 1 Plasmid profiles of *Lactobacillus plantarum* isolates from uninoculated silage. Reference plasmids from E. coli V517 lanes 14 and 28; MGD inoculant product (MGD286) lane 27; Chr, contaminating chromosomal DNA (Hill and Hill 1986).

which were introduced. This proves that the natural population of fermenting organisms can be altered by inoculation of competitive strains.

Physiological studies coupled with plasmid analysis on all the lactic acid bacteria isolated in this experiment also showed that populations of homofermentative and heterofermentative organisms shifted during the fermentation. Heterofermentative organisms produce gas as well as acid, and thus more of the nutrients in the original crop are lost due to their activity. Not only did the desirable homofermentative organisms, *L. plantarum*, predominate sooner in the inoculated silage, but after two months, the numbers of *L. plantarum* declined in both the control and the inoculated silos. A large amount of field data is available to show that these particular organisms produce a high quality, stable silage. The Hills' work also shows, therefore, that isolation of organisms from older silage would not necessarily produce the strains which were originally responsible for the successful fermentation. This is an excellent example of the way in which plasmid profiling can be used to study microbial ecology and also how understanding that ecology can lead to strategies for improving research approaches to inoculants.

A final example is an experiment on the persistence of *Bacillus sp.* strain (MGD311) on soybean roots. The organism tested in this experiment had shown positive effects on plant vigor in greenhouse trials and improved yield in some field trials. The gram positive bacilli are attractive for product development of microbial seed inoculants because they frequently elaborate and excrete products inhibitory to bacteria and other plant pests and could thus be useful for biological control. Also, their ability to sporulate and survive heat and drying would simplify product formulation. However, among the common soil microorganisms, the gram negative pseudomonads are widely regarded as active plant root colonizers and candidates for protective inoculants, while bacilli are thought to be saprophytes that do not selectively live in association with roots. The experiment was conducted to determine whether a particular organism with known beneficial effects might in fact persist in the rhizosphere and, if so, for how much of the growing season.

Polyclonal antibodies to MGD311 were raised by hyperimmunizing rabbits. Cross reactivity to this antiserum was the preliminary selection criterion. Roots were dug in the field and cultured on various media. Colonies which resembled the inoculant were tested,

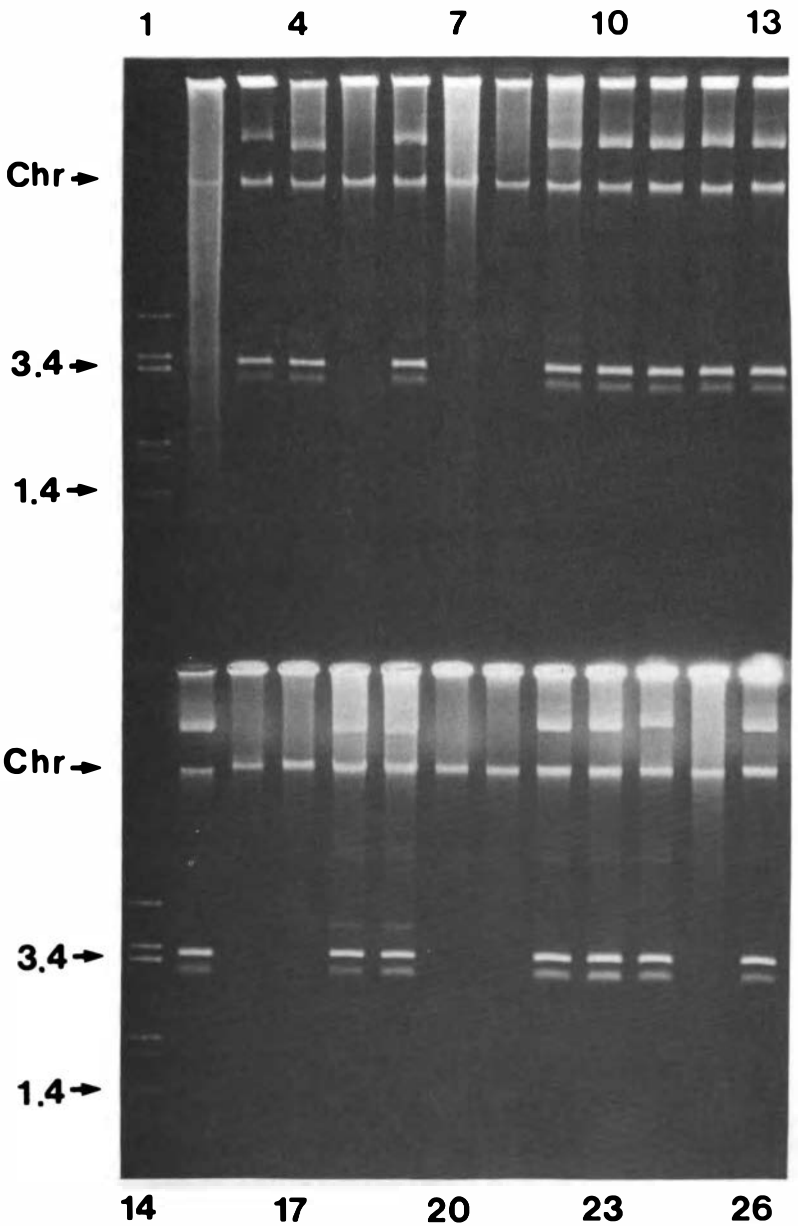

FIGURE 2 Plasmid profiles of *Lactobacillus plantarum* isolates from silage inoculated with MGD286 (reference lane 15) and MGD287. Reference plasmids from E. coli V517, lanes 1 and 14. MGD287 does not contain plasmids. Chr, contaminating chromosomal DNA (Hill and Hill 1986).

and those that bound the antibody were isolated for further analysis. Figure 3 shows antibody reactivity for organisms isolated from inoculated and control soybean roots through the growing season. Roots from treated seed initially had a higher level of cross-reacting organisms, which suggested survival of the inoculant. However, the control plot had a high background of immunopositive organisms, and both plots showed increased numbers at the end of the summer.

Therefore, further identification of the isolates was made by plasmid analysis. Bacilli found in soil frequently contain single large plasmids which are too large to be easily isolated or compared on the basis of molecular weight. In this case it was useful to digest the plasmid preparation with restriction enzymes and compare the profiles of the plasmid fragments. Different large plasmids have characteristic patterns of fragments as the lactobacilli have characteristic patterns of smaller plasmids. Figure 4 shows plasmid digests of organisms from the treated plot. Early in the growing season, antigenically similar isolates appeared identical to the inoculant. Late in the season, although a very large number of cross-reaction strains were isolated, none were identical to the inoculant. This was also true for late season isolates from the control plot.

This research has shown that soybean roots can be successfully colonized by a bacillus inoculant during early weeks of seedling growth. Late in the season, organisms in the group related to this bacillus become a major part of the rhizosphere flora as soy roots become senescent. This competition may influence the persistence of the introduced organism.

CONCLUSION

The transfer of knowledge of microbial physiology into practice as exploitation of inoculants is presently hindered by a lack of fundamental information. Research on microbial ecology at the level of specific strains should be encouraged in all agroecosystems—host/pathogen interactions, saprophytic life stages of pathogens, legume/rhizobium interactions, colonization of plant roots by nonpathogenic bacteria and fungi, fermentation of silage, decomposition of wastes, and colonization of the rumen and gut.

In some cases, plasmid profiles are suitable for tracking individual strains in these environments. In other cases, probes may be developed by inserting unique, nonfunctional DNA fragments into

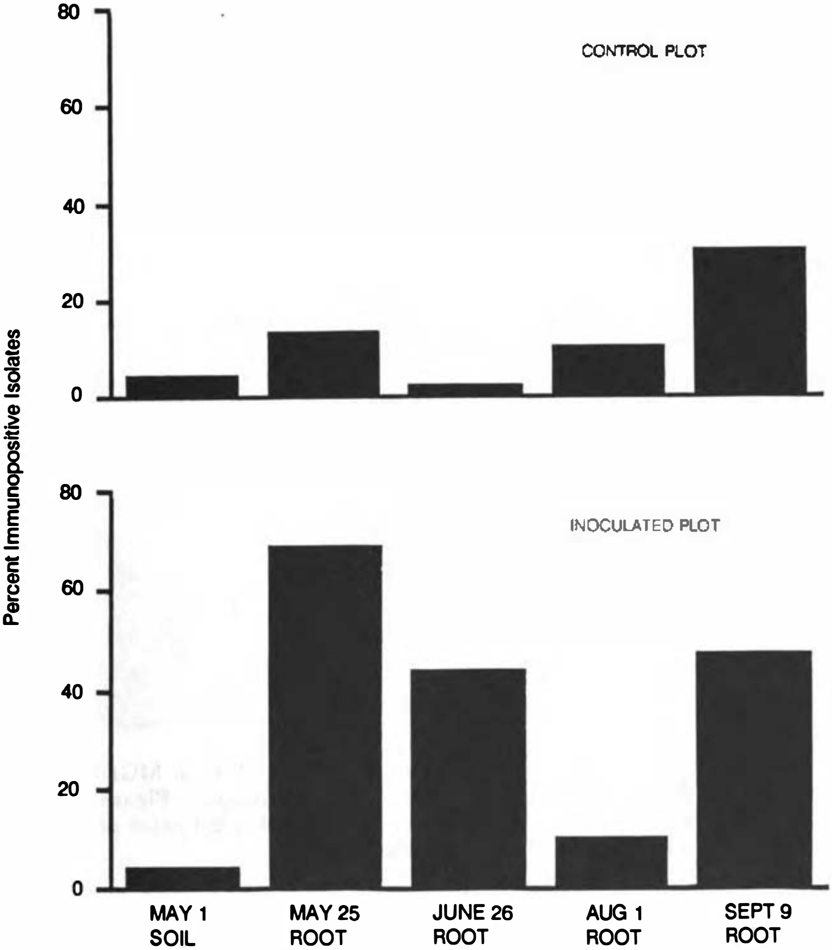

FIGURE 3 Recovery of organisms cross-reacting with polyclonal antibody to seed inoculant MGD311. Bacterial isolates from roots or soil with similar colony morphology to MGD311 were rated for strong positive reaction to anti-MGD311 by immunoblot assay (Brown and Hendricks, unpublished).

the organism. This should be clearly differentiated from the engineering of genes into organisms and should be supported as a critical step in expanding our knowledge. Acquisition of this basic knowledge will change what is now thought of as the potential for use of naturally occurring microbes as inoculants. This is an exciting promise for biotechnology in the future of agriculture.

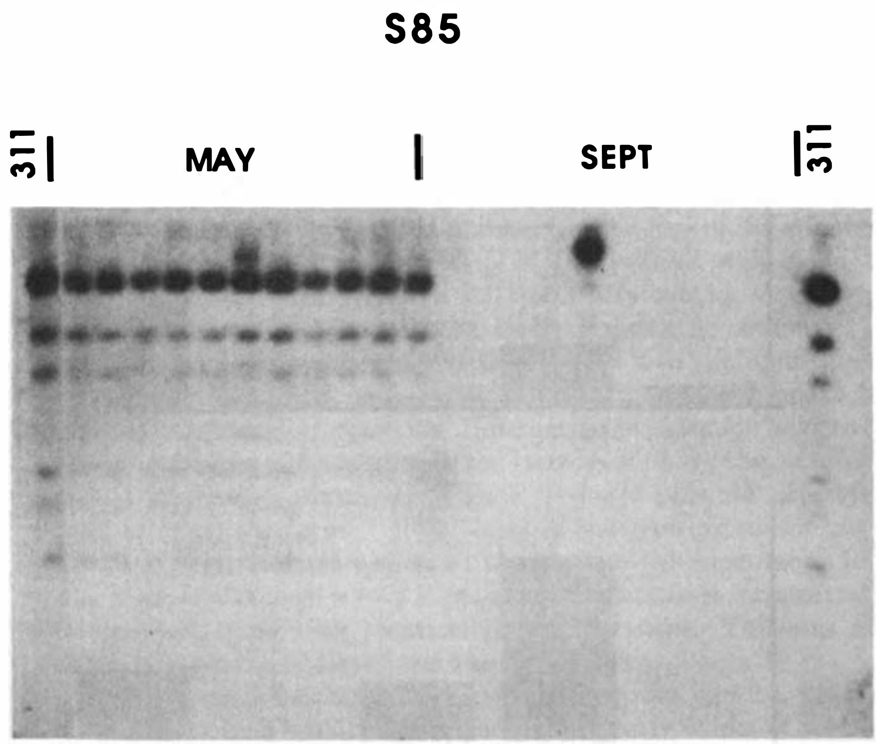

FIGURE 4 HindIII restriction fragments of plasmid DNA from MGD311 and cross-reacting field isolates from the treated plot as shown in Figure 3. The month in which the cross-reacting isolates were recovered is indicated above the appropriate lanes (Brown and Hendricks, unpublished).

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Agricultural Development Through Innovative Research and Application of Biotechnology

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This paper examines some of the problems that confront world agriculture and related environmental issues, especially in Third World countries, and discusses some of the new approaches which have been initiated by the U.S. Agency for International Development (AID) in an effort to seek solutions to these problems. The focus is on innovative AID research programs and the application of biotechnology to crop improvement and to agriculture in general. Research policy, priorities, and applications are emphasized rather than state-of-the-art or recent technological advances in the field.

EMERGING PROBLEMS IN WORLD AGRICULTURE

In the last half century, phenomenal progress has been made in increasing agricultural productivity. In the case of the United States, production levels have more than doubled even though the area of the land under cultivation has actually declined. This remarkable progress has been made possible by advances in agricultural science, particularly the development of agricultural chemicals, improved plant varieties, and farm mechanization.

As a result of the early discoveries by the Czechoslovak-born Gregor Mendel, a foundation was laid in genetics which enabled plant breeders to produce new and improved crop varieties. These varieties were not only high-yielding, but many of them possessed desirable characteristics such as resistance to diseases or pests.

Unfortunately, it was soon discovered that improved breeding practices have their limitations. Many generations may be needed to develop a desired strain, and some important genetic traits may be lost as a result of intensive in-breeding. Furthermore, genetically superior plants may require high levels of crop management, including the input of expensive fertilizers and extensive use of pesticides and herbicides. The continued application of the latter may, in turn, bring about accumulation of toxic residues in the environment. These problems are further compounded by the possibility that a high degree of in-breeding and the narrowing of the genetic base of widely cultivated crops can increase the susceptibility of crops to major disease outbreaks. Intensive use of irrigation, which is a prerequisite for a maximum crop output in arid regions, can bring additional problems since heavily irrigated soils are plagued by salt buildup and mineral toxicities.

Agricultural problems are not limited to any one region and are particularly acute in Third World countries where farmers still struggle to extract whatever food they can from marginal soils. Continued and expanded use of marginal land must inevitably lead to trace element deficiencies and the need for increased use of remedial fertilization, which is too costly for a poor farmer to afford. These problems are further accentuated by the ever-increasing pressure of population growth. If the world's population continues to grow at 1.8 percent annually, food production will have to double in the next forty years to keep pace. In addition to the need to feed many more people, food will have to be produced from inferior soil under poor climatic and continuously deteriorating environmental conditions. Clearly, new ideas and new approaches are needed to cope with such a plethora of problems.

SEEKING SOLUTIONS THROUGH INNOVATIVE RESEARCH

To meet these and related challenges, in 1981 the U.S. Congress established an innovative new Program in Science and Technology Cooperation (PSTC) to be administered by AID. AID has a long tradition of assisting developing countries to achieve self-sustaining economic growth and to improve the well-being of the poor majorities of their populations. The application of science and technology to development over the last three decades has been perhaps the single most important source of sustained and broadly-based economic and social progress among the less developed countries (LDC).

The new program mandated by Congress was designed to:

- assist developing countries to strengthen their own scientific and technological capacity to undertake the research and experimentation necessary for development;
- support research in the United States and developing countries on critical development problems;
- foster the exchange of scientists and technological experts with developing countries.

The purpose of a separate program for these activities was to encourage AID to take a more innovative and collaborative approach to the problems and processes of development research and technology transfer.

In late 1980, AID created the Office of the Science Advisor, responsible to the AID Administrator, as the focal point for more innovative and collaborative approaches to development research, technology transfer, and related capacity building. The Office identifies the scientific and technological needs and opportunities in developing countries and maintains liaison with scientific leaders in both developed and LDC countries.

The Office began a worldwide search for new ideas and innovative approaches worthy of support. It met with LDC science attachés, with LDC scientists and institutions, and with U.S. leaders in science and development. It also developed new mechanisms for soliciting, reviewing, and managing research.

The PSTC program invites scientists from around the world to submit research proposals directly to AID for consideration and rigorous peer review. The response from LDC scientists and institutions has been enthusiastic, as the annual submission of proposals has increased from 120 in 1981 to 600 in 1986. The quality of submissions has also improved significantly in both scientific proposals and development ideas. Several of these grants have already stimulated an increased interest in research at the highest levels of LDC national governments. More than 60 countries now participate in this innovative program.

In addition to this program, AID supports the U.S. National Academy of Sciences Board on Science and Technology for International Development (BOSTID), whose programs provide financial support to LDC researchers. BOSTID also convenes workshops, organizes advisory teams, and issues study reports on selected research opportunities. Over 600,000 copies of 50 publications have been distributed throughout the world, and they have had a large and influential readership.

RESEARCH PRIORITIES

The PSTC program seeks new research ideas in the natural sciences, such as biology and chemistry, and in engineering that can be adapted to problems facing developing countries. Research means the testing of specific scientific hypotheses or the development of new technologies through organized observation in an experimental setting.

From its inception, the program has received some 3,000 pre-proposals in open competition. Based on past experience and on several meetings on specific new technologies, six priority areas of investigation known as "Research Modules" have been identified for special emphasis and funding. These six Modules are:

1. *Biotechnology/Immunology* in human and/or animal systems, including recombinant microbiology, monoclonal antibodies, and related immunological techniques for better and more rapid diagnosis, immunotherapy, vaccine development, and related health applications;
2. *Plant Biotechnology*, including tissue culture research, protoplast fusion, somaclonal variation, and recombinant microbiology to improve food and fiber crops; also improvement of drought tolerance and enhancement of resistance to disease, insecticides, and/or herbicides through studies of gene expression, transfer, and regulation;
3. *Chemistry for World Food Needs*, particularly biochemical growth regulation in plants and animals, soil chemistry, soil/plant/animal relationships, innovative agricultural and food chemistry, biochemistry, studies of natural pesticides from plants, and the chemistry of integrated aquaculture systems;
4. *Biomass Resources and Conversion Technology*, emphasizing improved, renewable production and innovative, efficient use of woody biomass and tropical grasses for fuel, fodder, and higher value chemicals, as well as new and simpler methods to identify economically useful biomass products and by-products;
5. *Biological Control* of vectors transmitting human, animal, and plant diseases, emphasizing ecologically acceptable interruption of disease transmission based on microorganism/host/vector relationships, genetics, biochemistry, immunology, natural predation, and pathobiology;

6. *Diversity of Biological Resources*, emphasizing innovative research on terrestrial and aquatic plant/animal/microbial systems of economic promise for development. This includes new methods for identifying economically useful species and products, restoration and optimization of habitat for species and ecosystem maintenance and productivity, and development of new molecular-genetic methods for the above. Conventional breeding, taxonomic studies, and distribution surveys are normally excluded.

Occasionally, support is provided for selected innovative research proposals in two additional somewhat broader areas ("Premodules"):

- *Engineering Technology*, such as structural/materials research, mechanical engineering, and electrical engineering, including low-cost information and computer technology; and
- *Atmospheric, Marine, and Earth Sciences*, such as meteorology, hydrology, geology, seismology, remote sensing for natural resource analysis, and the better utilization and preservation of coastal zones.

THE BIOTECHNOLOGY EMPHASIS

Much of the current research carried out under the PSTC program centers on biotechnology, an area which is rarely defined properly. Some equate it with molecular gene splicing, recombinant DNA technology, and genetic engineering while others, including agriculturists, view it more broadly as an integrated use of the biochemistry, microbiology, and engineering sciences to achieve technological application of the capacities of plants, animals, microbes, and culture tissue cells.

The concept of biotechnology is not new. Man has been utilizing biologically-based technologies since the dawn of civilization. The process of making beer, for example, is based on the conversion of carbohydrates to ethanol and carbon dioxide, and the process has had a long tradition and has reached a high degree of sophistication in Czechoslovakia. Furthermore, biotechnologies in the form of improved crops and livestock have been the cornerstone of agricultural production, particularly since the rediscovery of Mendel's laws which provided the scientific basis for plant breeding. Research in the last decades has proven that cultured tissue can regenerate whole plants, thus confirming the old "totipotency" concept which has led to the biotechnology revolution of today.

Of the various biotechnologies, plant tissue culture currently offers the most promise for plant breeding and improvement. The technique which may involve *in vitro* culturing of cells, tissues, organs, or embryos under aseptic and strictly controlled conditions has reached the level of sophistication comparable to that used in modern microbiology. The advantages offered by this technique include the capacity to screen large numbers of individuals in one suspension culture, the capability to select for natural and induced mutation, and the capability to produce identical clones from an individual cell selected for a desired trait. The high frequency of somaclonal variation in tissue culture combined with the selection process often results in cells with enhanced tolerance of the selective agent. The selected trait in the regenerated plants from such cells is often heritable. This phenomenon offers endless possibilities for producing new plants with superior characteristics.

A number of potentially valuable hybrids are aborted as young embryos because of the sexual incompatability existing among unrelated plant species. Using plant tissue culture techniques, immature embryos derived from such wide crosses can successfully be rescued from maternal tissues.

Another useful technique is somatic hybridization involving fusion of two somatic plant cells. To do this, the cellulosic cell wall has to be removed. The resulting protoplasts are then induced to fuse with other protoplasts. In this manner genetic information from two different species can be combined to produce artificial hybrids, such as crossing a potato with a tomato, which would not be possible through conventional plant breeding.

At a more fundamental level research has also been initiated towards actually placing new genes into plant cells or even whole plants. Gene transfer techniques rely on the applications of molecular genetics, commonly known as genetic engineering. This highly sophisticated research approach involves gene sequencing, gene isolation, gene cloning, development of appropriate gene vectors, gene transfer, gene expression, and gene transmission through subsequent generations.

Apart from improving the primary plant products such as seeds, tissue culture can also be used to produce a variety of useful secondary compounds on commercial scale, eliminating the problems due to seasonal variation, weather changes, or diseases. Application of biotechnology in the area of crop improvement includes genetic manipulations of microorganisms that interact with plants, such as in nitrogen fixation. The ultimate goal is to be able to grow major cereal crops without the necessity of using extraneous and very costly nitrogen fertilizer. To minimize environmental hazards and increase specificity, there is also a renewed interest in microbially-induced insecticides to control specific crop pests without harming natural predators or beneficial insects.

The PSTC program supports research efforts in all these areas, as illustrated by the titles of the projects set forth below:

- Tissue culture of banana and plantain for improving yield potential;
- New varieties of rice for saline and acid soil through tissue culture;
- Tissue culture for virus-free potato propagation;
- Genetic engineering approach to improvement of *Rhizobium* for tropical legumes;
- Isolation of strains, clones, and regeneration of plants from single cells of winged bean;
- New approaches of purification and immunological techniques for characterization and diagnosis of plant viruses infecting beans in Latin America;
- Utilization of plant protoplast biotechnologies for transfer of organelles having useful traits into crop plants;
- Application of monoclonal antibodies to rice virus epidemiology in the tropics;
- Interspecific hybridization in *Phaseolus* spp. through embryo culture techniques;
- Recombinant DNA in filamentous cyanabacteria;
- Tissue culture and microbial inoculation technologies for the improvement of *Alnus nepalensis* planting stock;
- Production of high methionine cowpeas by tissue culture.

This program represents only a fraction of the total effort which is being mounted in this area by the U.S. government and the private sector. What is different and unique about the AID program is the international orientation, the collaborative mode with the Third World countries, and the primary focus on the tropical and subtropical regions of the world. In 1986, AID allocated about 50 million dollars to biotechnology with about one-third expended on genetic engineering.

CONCLUSION

Among recent advances, biotechnology clearly stands in the forefront as the most promising approach to deal with the numerous emerging problems in agriculture today. If genetic engineering and related biotechnologies can be mastered, they can be used to improve agricultural crops and design new plants that are hardier, higher yielding, more nutritious, less expensive to produce, and less dependent on agricultural chemicals such as pesticides, herbicides, or fertilizers. These techniques have also shown promise for growing crops on marginal lands, under acidic or sodic conditions, without regard to weather extremes, and without further deterioration of the environment.

To be sure, the biotechnological approach should not be viewed as a replacement for the more conventional agricultural measures. For maximum effectiveness, biotechnology will have to be used in conjunction with the traditional agricultural practices currently used by plant breeders, soil scientists, and pest management specialists.

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Sludge Thickening: A Biotechnological Approach

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In recent decades rapid population and industrial growth have required more rigorous water pollution control measures which in turn have caused a considerable increase in the use of biological wastewater treatment facilities.

Even after preliminary treatment, many municipal and industrial wastewaters would be highly polluting if discharged into a watercourse because of their biological oxygen demand (BOD) content. The activated sludge process is frequently chosen as the secondary treatment process because of the high BOD reductions usually achieved, and in many countries it is the most commonly used method for biological treatment of wastewater.

In order to maintain optimum process conditions, waste impurities that are converted into new biomass (activated sludge) have to be considered against the rate at which solids are wasted from the activated sludge process. This so-called *waste-activated sludge* is removed from the system as a very dilute suspension containing 0.3 to 1.2 percent of suspended solids, depending on the type of activated sludge plant and the plant loading.

Waste-activated sludge contains between 98.7 and 99.7 percent water. Water is found in the solid particle cells adhering to and absorbed by the particles, in the capillary spaces, and in the cavities formed by a number of solid particles (Müller 1971). It is the water in these different locations that has to be removed to reduce the volume of the sludge.

Many existing treatment plants employ gravity thickeners, air

TABLE 1 A comparison of sludge thickening methods

Method	Polyelectrolyte addition	Space requirement	Energy consumption	Thickened sludge concentration
Gravity thickener	No	Large	Low	≤ 3 % DS
Air flotation thickener	Yes	Large	High	≤ 5 % DS
Centrifugation	No	Small	High	≤ 8 % DS
Bioflotation	No	Small	Low	5-8 % DS

flotation thickeners, or centrifugation for sludge treatment. But there is another method of sludge thickening which has been developed at the CSAV Institute of Microbiology (Barta et al. 1984a). This process involves two biological steps—flocculation and flotation. Both processes are based on enzymatic activity of microorganisms present in activated sludge. A comparison of the available techniques is summarized in Table 1.

Bioflotation thickening of sludge has some advantages over other alternatives, especially very low energy consumption and small space requirements. The biological processes which are utilized during bioflotation are dissimilatory denitrification or nitrate respiration. In dissimilatory denitrification, nitrate serves as the hydrogen acceptor in the oxidation reduction reactions of the carbon substrate to provide energy for cell growth. It is converted to gaseous end products—principally nitrogen—by heterotrophic bacteria. Biological denitrification is achieved under conditions of low (< 1 mg/L) or zero oxygen concentrations. A wide variety of common facultative bacteria present in activated sludge, such as *Pseudomonas*, *Micrococcus*, *Achromobacter*, *Denitrobacillus*, *Spirillum*, and *Bacillus*, have been reported to accomplish denitrification under anoxic conditions (McCarty and Haug 1971).

Dissimilatory nitrate reduction (denitrification) proceeds via nitrite to nitrogen oxide and nitrogen. The end product depends on the system pH. Nitrogen is the end product if the pH is above 7.3; below 7.3 nitrous oxide is produced (du Toit and Davies 1973).

In the bioflotation process it is necessary to enhance denitrification activity by controlled addition of nitrates into the waste activated sludge. In the first stage of the process the physical structure of the sludge is changed, and flocks are formed. In the second stage gaseous products of the denitrification are evolved and flotation occurs. Organic substances present in the sludge liquor serve as a carbon source of dissimilatory denitrification. It is not, therefore, necessary to add an external source of organic carbon in most cases.

After laboratory tests with good results the new method of bioflocculation and bioflotation was tested in a pilot plant installation. The pilot plant was built at the mechanical biological wastewater treatment plant which treats approximately 15,500 m^3/d of wastewater. The wastewater was a mixture of municipal wastewater from a town with a population of 27,000 and industrial wastewater mainly from slaughterhouses and the textile industry. The total load was a 76,000 population equivalent. The mean BOD_5 was 164 mg O_2/L. A diagrammatic layout of the pilot plant is shown in Figure 1.

The process starts with nitrate addition to the waste-activated sludge. The nitrate is added into the mixing tank in the form of a 10 percent solution of calcium nitrate. The hydraulic retention time in this vessel is very short, approximately five minutes.

In the reaction tank the activity of enzyme nitrate reductase is induced and flocculation occurs. At the same time coagulation of colloid particles takes place. The hydraulic retention time in this tank ranges from 30 to 180 minutes according to different sludge properties. Flocculated waste-activated sludge is then pumped into the flotation tank. The volume of this tank in the pilot plant is 7.84 m^3. The hydraulic retention time ranges from 50 to 180 minutes. In this tank the denitrification proceeds. The bubbles of gaseous end products of denitrification lift the sludge particles to the surface where a layer of thickened sludge is formed. The flotated thickened sludge is wiped away using hooks from the top of the flotation tank. The sludge liquor is drained off from the lower part of the flotation tank.

This pilot plant was operated for more than two years. The results of the operation are summarized in Table 2; the values given are the mean of a one-year operation.

The operation parameters of the flotation unit were as follows: The mean flow of the waste-activated sludge into the bioflotation pilot plant was 5.19 m^3/h. Concentration of total suspended solids was 2.96 g/L, and the hydraulic retention time 1.41 h. The temperature

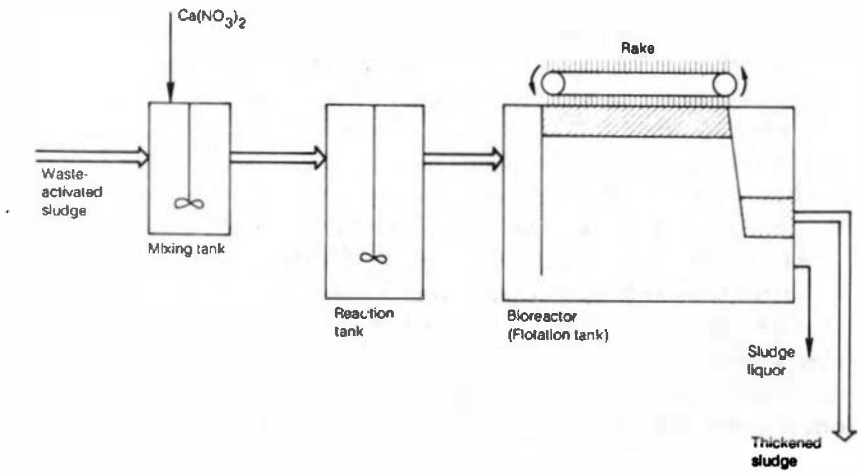

FIGURE 1 Diagrammatic layout of the bioflotation pilot plant unit.

TABLE 2 Results of bioflotation pilot plant operation with reaction tank

	Influent (Waste-activated sludge	Thickened sludge	Effluent (sludge liquor)	Reduction %
Suspended solids (g/l)	2.96	42.82	0.22	--
BOD_5 (mg O_2/l)	291	--	91	68.6
COD (mg O_2/l)	495	--	232	53.0
NO_3 (mg/l)	20.2	--	29.6	--

TABLE 3 Results of the bioflotation pilot plant operation without reaction tank

	Influent (waste activated sludge)	Thickened sludge	Effluent (sludge liquor)	Reduction
Suspended solids (g/l)	3.15	45.88	0.36	--
BOD_5 (mg O_2/l)	372	--	94	74.7
COD (mg O_2/l)	624	--	267	57.2
NO_3 (mg/l)	24.0	--	27.0	--

Nitrate dose = 95 - 110 mg N - NO_3/l
Hydraulic retention time = 2l/h
Sludge temperature = 15 - 18° C

of waste-activated sludge ranged from 12 to 24 degrees Centigrade. The dose of calcium nitrate was 128 g/m^3 of waste activated sludge. The mean energy consumption was 0.25 per 1 m^3 of waste-activated sludge (Barta et al. 1984b).

In the next series of tests the bioflotation unit was changed. It was operated without the mixing tank and the reaction tank. Instead of these vessels, a static mixer for homogenization of the mixture of waste-activated sludge with calcium nitrate solution was used. All bioflocculation and bioflotation reactions took place in the flotation reactor. The hydraulic retention time in the flotation tank was prolonged to two hours, a period sufficient for satisfactory sludge thickening. In fact, this flotation unit arrangement decreased the hydraulic retention time of the whole system to nearly one-half. The results of the operation are summarized in Table 3.

It can be seen that the performance of the bioflotation unit in this arrangement was nearly the same as in the first case. The BOD_5 and chemical oxygen demand (COD) reduction was slightly higher. The waste-activated sludge volume reduction was higher than 90 percent.

It is very important that during the bioflotation process the

BOD_5 and COD values of sludge liquor which is commonly sent back for biological treatment are substantially decreased. In other thickening processes this effect cannot be achieved because all other processes utilize physical methods which cannot influence these values.

Even more promising results were obtained when the bioflotation unit was operated batch-wise. In this case the thickened sludge had a total suspended solids concentration of more than 80 g/L. This is particularly important when the bioflotation process is utilized at small wastewater treatment plants which serve communities with a few residents. In this case, only small volumes of waste-activated sludge have to be thickened and the batch process is very suitable. Longer hydraulic retention time helps attain a higher total suspended solids concentration in thickened sludges. In this case investment costs are much lower.

The bioflotation process is suitable for nearly all plants which treat wastewater biologically. According to our experience it cannot be used in plants which treat wastewater with very low concentrations of nitrogen, e.g., wastewater from the pulp and paper industry.

Biological flotation and thickening has the following advantages over other alternatives:

- Polyelectrolyte is not required.
- Energy consumption is very low.
- Space requirements are small.
- During bioflotation, the BOD_5 and COD are substantially reduced.

Because of very low energy consumption, technical simplicity, and low investment and operation costs, bioflotation is a very promising process for waste-activated sludge thickening.

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Appendix 1

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Appendix 2

Final Document

NAS-CSAV Workshop on
Agricultural Development and Environmental Research

CSAV South Bohemian Biological Center
České Budějovice, Czechoslovakia

April 7 - 10, 1987

***Selected Problems Identified by Participants*:**

- Lack of adequate attention to ecological aspects of intensified use of agricultural land, including spatial organization of production, urbanization patterns, effective land utilization, and use of mountainous areas
- Lack of comprehensive approaches to evaluation of human activities in the landscape
- Increased disruption of vegetation, including trees and shrubs, as life-supporting and stabilizing systems in the rural landscape
- Degradation of soil through erosion, salinization, sodification, organic matter deterioration, and toxic pollutants
- Poor soil management practices due to lack of understanding of soil behavior, poorly developed methods for soil analysis, and inadequate use of biotechnologies
- Degradation of surface waters by silt, algae, and toxic pollutants
- Inadequate knowledge as to the current extent of contamination of surface water and groundwater and the associated risks to human health
- Lack of understanding of the properties of pesticides, of soil, and of agricultural practices that influence pesticide migration to water resources
- Increasing exposure to toxic chemicals of human populations, including agricultural workers, and of plant and animal components of ecosystems in agricultural areas

including agricultural workers, and of plant and animal components of ecosystems in agricultural areas

- Necessity of improving plant protection by integrated pest management, reduction of amounts of chemicals, and use of natural resources
- Lack of tolerance of plants to pathogens and other environmental stresses
- Damage caused by parasites in ecosystems created or altered by human activities
- Lack of interdisciplinary research to examine the interactions of plant growth, pest development, and the environment
- Limitations on traditional methods to improve crop productivity with minimum environmental damage
- Possible climatic changes from increased levels of carbon, nitrogen, and sulphur compounds in the atmosphere
- Impact of acid deposition on biological systems
- Excessive use in agricultural systems of inputs which are heavy consumers of energy
- Need for alternative sources of nitrogen to replace fertilizers
- Lack of effective and ecologically safe methods for waste disposal
- Need for more rapid application of research results

Selected Research Priorities:

- Improve understanding of how the natural resource base can be used most effectively in intensifying agricultural activities with minimum adverse ecological effects
- Develop and apply systems analysis techniques in assessing and managing natural and altered ecosystems
- Refine and adopt methodological approaches to resolving problems related to ecologically optimal uses of landscapes
- Study the taxonomy of soil organisms, their role in soil farming, soil microorganisms, and soil fauna
- Increase understanding of the biology and microstructure of soils
- Investigate nutrient transformations and losses in ecosystems
- Investigate commerical husbandry in ecosystems created or modified by human activities, including animal density considerations
- Develop and apply exposure assessment techniques, including techniques for estimating human exposure to toxic chemicals through inhalation, ingestion, and dermal absorption and associated pharmokinetic aspects

- Develop and apply ecological risk assessment techniques
- Evaluate techniques for minimizing waste generation, including recycling, for applying bioengineered organisms to degrade hazardous wastes and for assessing environmental transport and fate of waste products
- Determine the effects of acid deposition on biological systems
- Investigate interspecies relationships in weed/crop systems under different ecological regimes as a basis for reducing the amounts of herbicides
- Encourage basic research on biologically active compounds, their testing and application
- Expand research on genetic engineering for increasing agricultural productivity and for developing plant species which are resistant to diseases and pests
- Expand the base of knowledge necessary for identifying new organisms which can be used in biological control and for improving the properties of existing biological agents
- Develop simple and inexpensive programs for monitoring pest abundance
- Develop agricultural systems and system components which are less dependent upon high energy inputs, which maintain productivity, and which have enhanced ecological acceptability
- Explore plant/microbe relationships, particularly to enhance biological nitrogen fixation
- Improve both partners [legume and rhizobium] of nitrogen fixation
- Pursue conventional and biotechnological breeding programs for crops with lower fertilizer requirements for acceptable yields
- Study the expression of transferred genes related to monocotyledonous plants
- Explore the metabolic mechanisms controlling the rate of photosynthesis
- Encourage research on the mechanism for controlling plant regeneration from cells and tissues

Selected Themes for Cooperation:

- Improved understanding of the concepts and potential of landscape ecology as a planning and management tool
- Methods for investigating ecological systems, structures, and processes, and for evaluating ecological stability of landscapes

- Methods and models for ecological optimization of land use and management
- Soil biology, including simulation modeling
- Mathematical methods for modeling ecosystems
- Role of soil organisms in nutrient cycling and in soil microstructure formation connected with organic farming
- Relationships among parasites, hosts, and environments, particularly in terms of immunology and resistance
- Field studies of pesticide leaching and movement in water resources
- Laboratory investigations of transformation rate constants and properties for pesticides of particular concern
- Monitoring exposure of agricultural workers to pesticides
- Effects of chemicals on reproductive systems as a biomonitoring technique
- Ecological exposure and risk assessment methodologies
- Biodegradation techniques for reducing waste disposal problems
- Biological and genetic control of pests
- Basic research on biologically active compounds for pest and weed control and their application
- Use of genetic engineering in the development of resistance to plant diseases and other pests
- Optimization of pest control through development of improved pest management systems
- Study of weed control and the maintenance of ecological balance
- Use of biotechnology to develop new crop breeding methods
- Biotechnological approaches to enhanced agricultural productivity
- Development of agricultural systems which are less dependent on high energy inputs
- Breeding of legumes for improved nitrogen fixation
- Effects of air pollutants such as SO_2 on selected biological species, including use of remote sensing

Possible Mechanisms for Increased Scientific Cooperation:

- Use of interacademy program:
  - exchanges of individual scientists nominated by CSAV and NAS
  - bilateral workshops and symposia

- Cooperative research projects developed by U.S. universities and CSAV institutes
- Informal scientist-to-scientist cooperation with minimum of red tape:
  - exchanges of publications and data
  - exchange visits
  - coordination of research projects
  - joint publications
- More active involvement of U.S. and Czechoslovak scientists in activities of UN agencies (e.g., WHO, UNESCO, FAO, WMO, UNEP) and of international scientific unions
- Greater participation of U.S. and Czechoslovak scientists in scientific meetings in Czechoslovakia and the United States, respectively
- Exchange of genetic materials
- Exchange of information on institutional capabilities and research projects being planned and in progress in the two countries
- Visits by American industrial research scientists to Czechoslovakia to become acquainted with scientific activities of possible commercial interest to U.S. companies

Appendix 3

List of Associated Visits

- CSAV Institute of Entomology, České Budějovice
- CSAV Institute of Soil Biology, České Budějovice
- CSAV Institute of Parasitology, České Budějovice
- CSAV Institute of Landscape Ecology, České Budějovice
- CSAV Institute of Experimental Botany, České Budějovice
- Agronomy Faculty, Agricultural University of Prague, České Budějovice
- Chelčice Cooperative Farm
- Slušovice Agricultural Complex
- Czechoslovak Ministry of Agriculture and Food, Prague
- Higher School of Economics, Prague
- Research Institute for Agricultural Machinery, Prague
- CSAV Institute of Economics, Prague
- CSAV Institute of Microbiology, Prague
- CSAV Institute of Organic Chemistry and Biochemistry, Prague
- CSAV Research Institute for Plant Production, Prague-Ruzyně
- Hydrometeorological Institute, Prague
- Academy of Agricultural Sciences, Prague
- Charles University, Prague
- Agricultural University, Prague
- SAV Institute of Experimental Biology and Ecology, Bratislava
- SAV Institute of Experimental Phytopathology and Entomology, Bratislava
- SAV Institute of Landscape Ecology, Bratislava
- SAV Institute of Geography, Bratislava
- SAV Institute of Molecular Biology, Bratislava
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