The Crafoord Prize

in the Biosciences
1987

CRAFOORD LECTURES

Global stress in life-support ecosystems mandates input management of production systems

by

Eugene P. Odum

and

Living with complexity

by

Howard T. Odum

THE ROYAL SWEDISH ACADEMY OF SCIENCES

The Anna-Greta and Holger Crafoord Fund

The **Crafoord Fund** was established in 1980 by a donation to the Royal Swedish Academy of Sciences from Anna-Greta and Holger Crafoord.

The purpose of the fund is to promote basic scientific research in Sweden and in other parts of the world in the following disciplines:

- mathematics and astronomy
- the geosciences
- the biological sciences with particular emphasis on ecology
- rheumatoid arthritis.

Support to research takes the form of an international prize awarded annually to outstanding scientists, and of research grants to individuals or institutions. The awards are made according to the following rota:

Year 1 mathematics
Year 2 the geosciences
Year 3 the biosciences
Year 4 astronomy
Year 5 the geosciences
Year 6 the biosciences
Year 7 mathematics
and so on.

The research grant for rheumatoid arthritis is made every third year, but the prize is awarded only when a special committee has shown that scientific progress in this field has been such that an award is justified.

A certain portion of the grants is reserved for appropriate research projects at the various institutes of the Academy.

When the prize and the research grants are to be awarded in mathematics, astronomy, the geosciences or the biosciences, the first step is to define, in the light of current international scientific development, a research area of particular interest. The prize and the research grants are then awarded for work in this area.

The award - the **Crafoord Prize** - consists of a sum exceeding 1.3 million Swedish crowns, a gold medal and a diploma.

The Crafoord Prize is awarded at a ceremony held at the Royal Swedish Academy of Sciences on a **Crafoord Day** in early autumn. On this occasion, the prizewinner gives a public lecture, the **Crafoord Lecture.**

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His Majesty the King of Sweden (to the right) together with (from the left) Mrs Elizabeth Odum, Mrs Martha Odum, the prizewinner Howard T. Odum, the donor, Mrs Anna-Greta Crafoord and the prizewinner Eugene P. Odum. Photo: Boo Jonsson, Svensk reportagetjänst.

The Royal Swedish Academy of Sciences has awarded the Crafoord Prize for 1987 jointly to Professor Eugene P. Odum, University of Georgia, USA and Professor Howard T. Odum, University of Florida, USA for their pioneering contributions within the field of ecosystem ecology. Their fundamental findings have strongly promoted our understanding of the dynamics of natural systems and formed a scientific base for the long-term exploitation of the natural resources including pollution abatement.

On September 23, 1987 the prizewinners Eugene P. Odum and Howard T. Odum received the Crafoord Prize from the hands of His Majesty the King of Sweden at a ceremony at The Royal Swedish Academy of Sciences.

Eugene P. Odum has through numerous works formed the present basic picture of the structure and function of ecosystems. His textbook "Fundamentals of Ecology" published in 1953 has had an enormous impact on the scientific progress of ecology. Here the established foodweb structure of the natural systems were coupled to be the circulation of oxygen, carbon, nitrogen, phosphorus and other elements to a total structural system of nature.

Howard T. Odum's epochal contributions to ecology counts a series of basic studies of the importance of solar energy for the biogeochemical cycles and the development of ecosystems. His unique ability to explain events or processes from a total system perspective is demonstrated in how classical studies of rivers, lakes, coastal systems, coral reefs and tropical rainforests. H. T. Odum early recognized the consequences in nature of man's use of fossil fuel, contributing an energy subsidy to the ecosystem besides solar energy. On the basis of the laws of thermodynamics he has formulated an unifying systems theory including the socioeconomic field which has initiated an animated research activity which can be expected to change society's valuation of the living natural systems.

Eugene P. Odum and his younger brother Howard T. Odum were the first to in depth comprise the activities of man in the studies of natural systems.

Crafoord Prizes Awarded

1982 in **mathematics** within the field of nonlinear differential equations
Vladimir I. Arnold, Moscow State University, USSR and
Louis Nirenberg, New York University, USA for their outstanding achievements in the theory of nonlinear differential equations.

1983 in **geosciences** within the field of large-scale movements of the atmosphere and the sea
Edward N. Lorenz, Massachusetts Institute of Technology, USA and
Henry Stommel, Woods Hole Oceanographic Institution, USA for their fundamental contributions in the field of geophysical hydrodynamics that in a unique way contributed to our understanding of the large-scale circulation of the atmosphere and the sea.

1984 in **biosciences** within the field of coevolution – the mutual adaption of organism populations in the natural environment
Daniel H. Janzen, University of Pennsylvania, USA for his imaginative and stimulating studies on coevolution, which has inspired many researchers to continued work in this field.

1985 in **astronomy** within the field of the interstellar medium including star formation and interaction with stars
Lyman Spitzer, Jr., Princeton University Observatory, USA for his fundamental pioneering studies of practically every aspect of the interstellar medium, culminating in the results obtained using the Copernicus satellite.

1986 in the **geosciences** within the field of isotope geology
Claude J. Allègre, L'Institut de Physique du Globe, France and
Gerald J. Wasserburg, California Institute of Technology, USA for their pioneering work in isotope geology.

1987 in the **biosciences** within the field of ecosystem ecology
Eugene P. Odum, University of Georgia, USA and
Howard T. Odum, University of Florida, USA for their pioneering contributions within the field of ecosystem ecology.

Crafoord Lectures

1982 **Vladimir I. Arnold:** On some nonlinear problems.
Louis Nirenberg: Mathematical methods in nonlinear problems.

1983 **Edward N. Lorenz:** Irregularity: a fundamental property of the atmosphere.
Henry Stommel: The delicate interplay between wind-stress and buoyancy input in ocean circulation: the Goldsbrough variations.

1984 **Daniel H. Janzen:** The most coevolutionary animal of them all.

1985 **Lyman Spitzer, Jr.:** Clouds between the Stars.

1986 **Claude J. Allègre:** Isotope geodynamic.
Gerald J. Wasserburg: Isotopic abundances:inferences on solar system and planetary evolution.

1987 **Eugene P. Odum:** Global stress on life-support ecosystems mandates input management of production systems.
Howard T. Odum: Living with complexity.

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Global stress on life-support ecosystems mandates input management of production systems

Eugene P. Odum

Institute of Ecology, University of Georgia, Athens, GA, USA

Growth of interest in ecology might be compared with the emergence of a tree from fertile soil. That fertile soil, of course, is the biological sciences in which the roots of ecology are firmly embedded. As the tree grows it interacts more and more with the physical environment – the atmosphere, the hydrosphere and the pedosphere. By analogy, interest in ecology has expanded from small scale, mainly descriptive, studies of organisms in relation to environment to larger scale, functional studies of the biotic and abiotic components as they interact and control each other, and as they are affected by human activities. Out of this expansion in both temporal and spatial scales comes the levels-of-organization hierarchy theory and the concept of the ecological system or *ecosystem.*

The term ecosystem was coined in 1935 by Sir Arthur Tansley, an English botanist and one of the founders of the British Ecological Society the world's first ecological society. Tansley's expertise was vegetation, but unlike many specialists he had very broad interests including geology, psychology, and philosophy of science and its methodology. His selection of the word "system" clearly indicated that he was not thinking of the ecosystem as a catch-all word for everything that affects vegetation, but as a suitable name for an organized unit. The key concept in his own words "is the idea of progress towards equilibrium, which is never, perhaps, completely attained, but to which approximation is made whenever the factors at work are constant and stable for a long enough period of time".

In 1925, ten years before Tansley's paper, physical scientist A.J. Lotka published a book entitled "Elements of Physical Biology" which introduced thermodynamics to ecology and essentially outlined the modern theory of the ecosystem as perceived by my brother and I. Lotka's basic thesis, which was developed in his spare time when he worked as an industrial chemist, was that the organic and inorganic world functioned as a single system with all components linked through thermodynamics in such an intimate way that it is impossible to understand the part without understanding the whole. It is interesting, and I think significant, that a biologist, Tansley, and a physical scientist, Lotka, independently come up with the idea of the ecosystem as a major functional unit of the biosphere. Because he coined the word "ecosystem" and it caught on, Tansley gets most of the credit which should be shared with Lotka.

Ecosystem research and application involve what we might call a *top down* approach (Odum and Polunin, 1986), as illustrated in Figure 1. Since ecosystems are thermodynamically far-from-equilibrium open systems there are three components that need to be considered: (1) the system itself, which can be any area of the landscape large or small, homogeneous or heterogenous, however one wishes to delimit it; (2) the input environment including energy, materials and organisms that flow into the system; and (3) the output environment including processed energy, materials and emigrating organisms. In the top down approach we assess the externals – the inputs and outputs – first then investigate the internals (the material cycling, energetics, populations, food webs and so on) second. We do this in whatever detail, and as far down the hierarchical scale, as is necessary to test the theory, answer the question or solve the problem. Such an approach, of course, contrasts with the *bottom up* or *reductionist* approach which starts with the smallest components and attempts to work up to the whole from there.

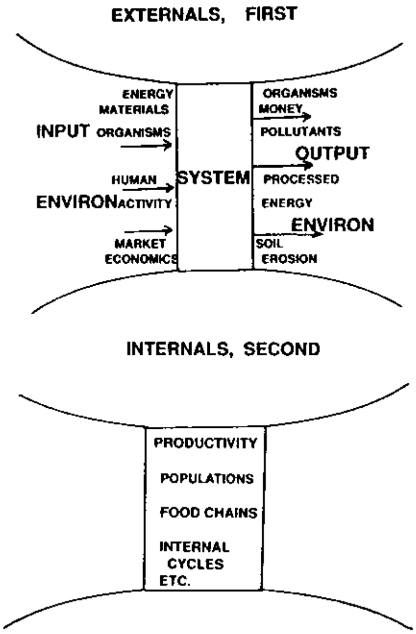

Figure 1. The top down approach involving assessing the ecosystem externals (inputs and outputs) first and the internals (populations, food, webs, material exchanges, etc.) second.

In this lecture I shall focus on these life-supporting ecosystems that provide our physiological necessities, and which are now being stressed on a global scale by human activities. I shall then outline the concept of input management as a means of reducing global stress, and illustrate with some recent research on agroecosystems.

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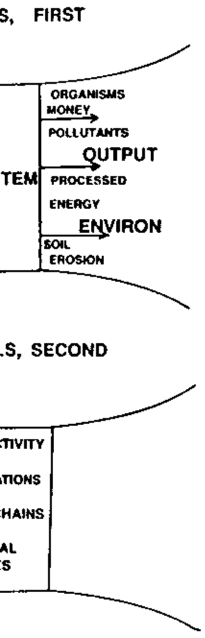

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The life-support environment

According to our best understanding of geological history, the earth did not support life in the beginning. The first tiny microorganisms that appeared more than two billion years ago had to survive in a very harsh environment; no oxygen, lethal ultraviolet radiation, extreme temperature variation. Over millions of years organisms interacting with geological and chemical changes gradually made the environment more hospitable by putting oxygen into the atmosphere and forming a green mantle over the surface where sunlight could be converted into all manner of food, supporting increased numbers and variety of creatures and, eventually humans. Despite periodic geological and cosmic catastrophies involving mass extinctions of species life on earth has managed to rebound after each catastrophe and continue to evolve towards increasing complexity and increasing control of the physical environment. Again, according to our best understanding of these periodic events, recovery followed the same general pattern that we observe in secondary succession following abandonment of a crop field or recovery of a forest after a severe storm. First, there was a rapid increase in number of individuals of surviving opportunistic species followed by a slower rate of increase in the diversity of species. Today, we are able to breathe, drink and eat in comfort because millions of organisms and hundreds of processes are operating in a coordinated manner out there in the environment. We tend to take all this work for granted because we don't pay money for most of it.

Since life-support is provided by a vast network of processes operating on different time scales we can not just go out into the environment and point and say, "look, there is our life-support system ticking away; its vital to our well-being and we must take good care of it", as we might point to and comment on our air-conditioner or the life-support module in a spacecraft. As the old proverb goes, "out of sight, out of mind", at least until trouble develops somewhere. Yet the ecological systems and processes that provide life-support can be identified, which is vital if we are to recognize and preserve them. To do so we must think about our environment as a whole and partition the landscape into functional units is some systematic manner.

In flying from Georgia, USA to Stockholm we get to view, in clear weather at least, a representative transect of the global landscape. For much of the flight we look down on large bodies of water, the ocean, large rivers, bays and so on. These are a very important part of earth's life-support module since they provide water and function as air purifiers, temperature moderators, and waste assimilators. Flying over land we may see large stretches of the same kind of habitat, – farmland, grassland, forest, – but where humans are concentrated the landscape is very "patchy" with fields, woodlands, towns, cities, suburbs, and highways often arranged in seemingly haphazard fashion. What we see in the areal view can be listed under three categories following the classification often used by students and professionals in the field of Landscape Design: *Fabricated, Domesticated* and *Natural Environments.* In less formal language we can think of the landscape as being divided into: *Developed Sites, Cultivated Sites,* and *Natural Sites.*

The fabricated or developed environment includes cities, industrial parks, transportation corridors (roads, airports), and contiguous lands. Neveh (1982) in his paper on "landscape ecology as an emerging branch of human ecosystem science" makes a distinction between the urban and rural human dominated landscape. From the standpoint of energy use we can think of the fabricated environment (whether urban or rural) as comprising *Fuel-Powered Systems.* And for much of the world today the fuel that runs our great cities and industries is fossil fuel. Urban-industrial developments actually cover a very small area of the total landscape but they are so energy intensive, i.e. requires very large amounts of high quality energy and create a large amount of waste heat and pollution, that they have an enormous impact on the other two environments. For example, *Energy Density* (amount to energy flow per unit of area per year) of an urban-industrial region may be 1000 or more times that of a forest. Not only does the city pour its waste products into the countryside, but it depends on this same countryside for almost all of it's life-supporting necessities.

The domesticated environment includes agricultural lands, managed woodlands, human-made ponds and lakes, and so on. Cultured plants and domesticated animals dominate this environment which is modified and managed to promote production of food and fiber as well as recreation and other direct human uses. This part of our landscape is made up of what ecologists often call *Subsidized Solar-powered Systems.* The sun provides the basic energy, but this source is augmented by a lot of human-controlled work energy in the form of labor, machines, fertilizers, etc, much of which is derived from fuels. Much of this environment, especially industrialized farms, is quite energy intensive and has considerable impact on the other two environments due to water, soil, fertilizer, and pesticide "runoff".

"Self-supporting" and "self-maintaining" are the key words in characterizing the natural environment. Natural areas operate without energetic or economic flows directly controlled by humans. These are the *Basic Solar-powered Systems* dependent on sunlight and other natural energies such as rainfall, waterflow and winds that are indirect forms of solar energy. Being self-maintained does not mean that the natural environment is not used or impacted by human activities. A National Forest, for example, may be grazed by sheep or have timber removed on a selective or rotating cutting basis. As long as these uses do not appreciable change the structure and function of the forest or its ability to reproduce itself then the forest qualifies as a natural area according to our definition. In contrast, a pine plantation with trees planted in rows and havested all at once in short rotation under strict human management is not a natural area but a cultivated one like a crop of corn.

Some years ago my brother and I published a joint paper (Odum and Odum, 1972) in which we made a case for the proposition that natural areas are a necessary part of man's total environment, not just desirable or luxury components. We also presented a simplified model that could be used to estimate the proportion of the landscape that should remain natural in order to avoid diminishing economic returns of scale in the human-made environment.

Based on these concepts we can now define the term, "life-support environment", in more precise terms. *Life-support Environment* is that part of the earth that provides the physiological necessities of life, namely food and other en-

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ergy, mineral nutrients, air and water. We use *Life-support System* as the functional term for environment, organisms, processes and resources interacting to provide these physiological necessities. By processes we mean operations such as food production, air purification, waste assimilation and so on. Some of these processes are organized and controlled by humans but many are natural and driven by solar and other natural energies. All life-supporting processes involve the activities of organisms other than man (plants, animals, microbes). In terms of the landscape, *Agricultural Systems + Natural Systems = Life-support Systems.* The former provide the one million Calories and the 15% protein required by each person for one year (admittedly, large number of people are not getting an adequate diet). The natural systems, as already noted, provide the other physiological necessities of life. The word *system* (dictionary definition: "regularly interacting items forming a unified whole") is the appropriate term since life-support involves not just area but plants, animals and microbes interacting with soil, atmosphere, water, minerals, etc.

Pollution stress on life-support systems

In one form or another pollution has been a local problem since the dawn of civilization (but especially since the industrial revolution) that has often altered the course of history. However, for the first time in history pollution resulting from human activities is becoming global in scale, as indicated by the increase in atmospheric toxification. Although somewhat arbitary it is instructive to consider pollution under two headings: *Point-source Pollution,* wastes and toxic substances that enter the environment through pipes, ditches and so on, and *Non-point Pollution* originating from numerous scattered or diffuse sources, such as automobile exhausts or runoff from agriculture fields. In recent years considerable progress has been made in reducing local municipal and industrial point-source pollution, but by and large it is non-point pollution that is stressing the global life-support environment. In other words, contamination of surface and ground water by agricultural and industrial chemicals, soil erosion from both urban and rural landscapes, increases in greenhouse gases, acid rain, reduction in protective ozone layers and other air pollution currently poses the greates threat to the earth's life-supporting atmosphere, soil and water bodies. Such non-point sources, unlike point sources, can not be controlled from the output side of a production system; *they can only be controlled from the input side by what I am choosing to call Input Management.* Input management requires a major change, almost an about face, in the philosophy and technology of management of agriculture, power plants, industrial plants, and other production systems.

These concepts are illustrated by the diagrams in Figure 2. As shown in Fig. 2 (top) attention for many years has focused on increasing outputs, i.e. yields. Whatever inputs that would increase yield on the short term were provided with little regard to efficiency or the production of unwanted output in the form of non-point pollution. From both the ecologic and economic standpoint it is evident that attention now needs to focus on the input side of the production system as shown in Fig. 2 (bottom). By increasing the efficiency of wasteful production systems costly and environmentally damaging inputs can be reduced with concurent reduction in non-point pollution without too much, if any, sacrifice of the yield of food, electricity, manufactured goods or whatever. And the profit margin may also be increased as input costs are reduced.

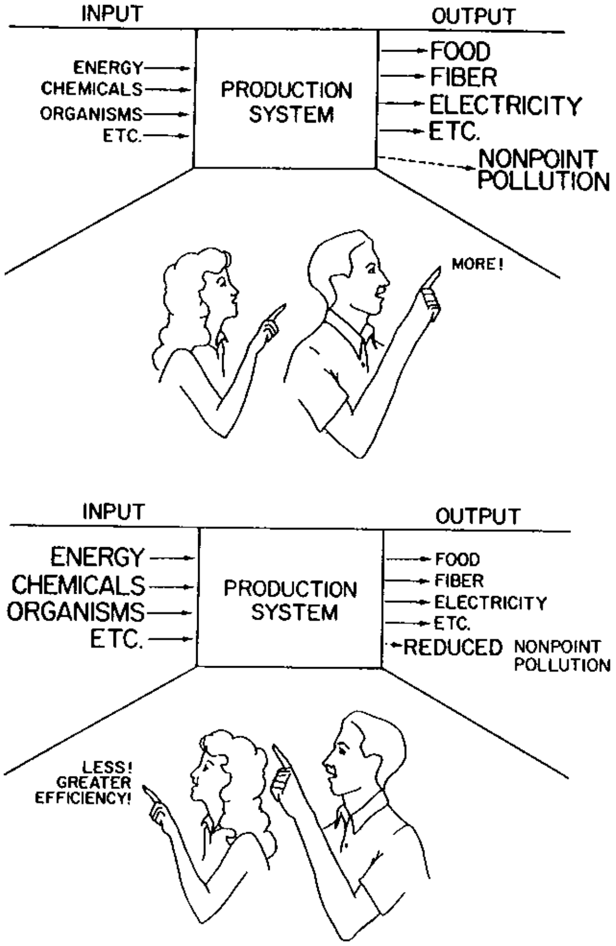


Figure 2. The "about face" on management of production systems. (top) Focus on input, such as yield, with consequences of increased non-point source pollution. (bottom) The shift to input management with focus on efficiency and reduction of environmentally damaging inputs so as to reduce non-point pollution.

Reduced input agriculture

Recent trends in farm system husbandry indicates that reduced input agriculture is indeed being researched and put into practice, which is good news for the future of earth's life-support systems. During the past several decades spectacular increases in the yield of grain and other cash crops have been obtained partly by selection of high-yielding cultivars but mostly by vast increases in the inputs of machine energy, fertilizers, irrigation water and pesticides. For example, we have recently plotted 50-year trends in Georgia agriculture as part of a comprehensive study of "The Georgia Landscape: A Changing Resource" (Odum and Turner, 1987). As shown in Figure 3 land in crops decreased two-fold between 1935 and 1985 but yields per hectare increased four-fold. During this same time period the volume of general purpose mineral commercial fertilizer applied to crops increased seven-fold and nitrogen eleven-fold. Increased use of insecticides and herbicides followed a similar trend. In general, crop yields have leveled off during the past ten years, indicating that diminishing returns are being reached for this kind of output management. Currently, the farmer may not be able to increase profits by increasing yields because the cost of producing a unit of crop may be greater than the market price of that unit due to rising cost of input subsidies.

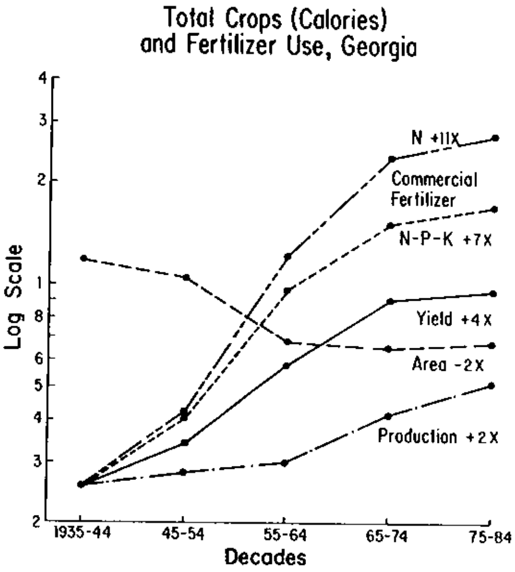
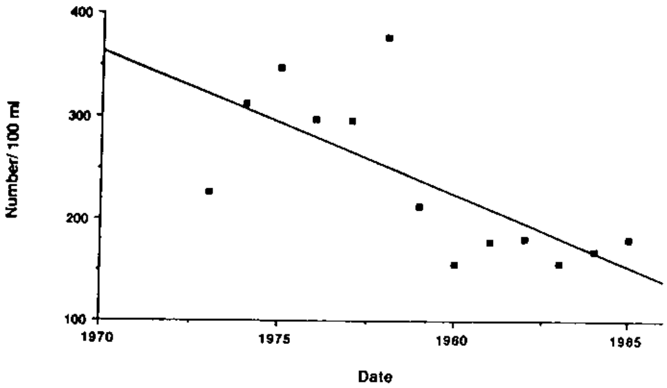


Figure 3. Fifty year trends in crop production and fertilizer use in Georgia. Annual yields of all major crops converted to common demoninator kilocalories and plotted on a semi-log scale so as to compare relative change.

Most important of all is the fact that increased use of agricultural chemicals in continuous monocultures is producing an unwanted increased output of non-point pollution, not only chemicals but soil. In reviewing water quality in major rivers of the United States Smith, Alexander and Wolman (1987) have reported that while sewage pollution has decreased over the past 15 years nitrates, pesticides and certain toxic metals have increased. In our Georgia study we have reaffirmed this trend for Georgia rivers as shown in Figure 4. Coliform bacteria, which can be considered an index for point-source municipal pollution, have declined (Fig. 4, upper) while total nitrate and nitrite nitrogen, an index of non-point pollution, has increased (Fig. 4, lower). In Illinois soil losses and runoff of toxic chemicals from continuous grain and soybean monocultures are producing a stress on the Illinois river greater than that caused when raw sewage from Chicago was dumped into the river many years ago. In 1975 it was estimated that 25 million tons of soil was moving annually from farmland into the river system, most of it settling into the shallow lakes and lagoons that are such an important part of this very productive river basin (Havera and Bellrose, 1985). The paradox is that efforts to enhance one part of the life-support environment (agriculture) are degrading other equally vital components (natural systems).

Five Year Flow Weighted Moving Averages of Fecal Coliforms in the Savannah River.



Five Year Flow Weighted Moving Average of Total NNitrate and Nitrite in the Savannah River.

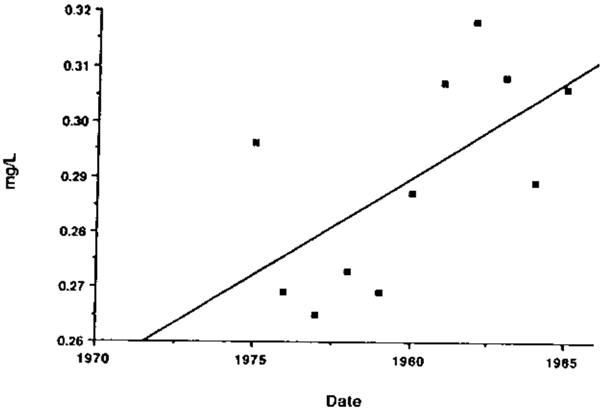


Figure 4. Comparison of trends in coliform bacteria (an index of point source pollution) and nitrogen (an index of non-point source pollution) in the Savannah River, Georgia, USA.

The scale of high input monoculture of cash crops has increased in recent decades because such a system has a number of advantages: it is adapted (1) to machine culture, (2) to large scale farming, (3) to large scale marketing infrastructure, (4) to areal spraying of pesticides, and (5) the economics of scale are favorable on the short term. On the other hand monoculture has the following disadvantages: (1) it is hard on the land (which needs rest and change of pace like other living systems), (2) required subsidies are increasingly expensive, (3) it's vulnerable to pest outbreaks, (4) genetic diversity tends to be reduced, and soil, water and chemical runoff are high. Over the long run monoculture is difficult to sustain and tends to be "boom and bust", i.e., rapid growth in yield followed by decline or even colapse. For example, see Adkisson (1982) for an account of the cotton "boom and bust" in Texas in the 1960's. The challenge to the new generation of biotechnologists is to genetically engineer cultivars that are not just high-yielding but are more efficient and require less fertilizer and other environmentally damaging chemicals.

Conservation tillage-crop planting systems that leave 30% or more of crop residues on the soil surface instead of plowing them under – and especially no-tillage – are examples of reduced-input practices that reduce unwanted outputs. In the hilly piedmont region of Georgia White, et.al. (1985) estimates annual soil losses under conventional tillage (plowing twice a year) to average 11 tons/acre for good farmland and 15 or more for marginal land. Annual nitrogen loses were estimated to be 10 and 15 lbs/acre, respectively. No-tillage involving winter clover and rye (the latter to provide mulch) and summer grain can just about eliminate such losses as shown by data in table 1. Where water is scarce or expensive maintaining a layer of mulch can greatly increase water retention (thereby reducing water loss) as shown in Table 2. Over the years soil quality is improved under conservation tillage rather than degraded as is too often the case with conventional tillage. Gebhardt, et.al. (1985) reports that cropland under various forms of conservation tillage is increasing rapidly in the USA with one-third of cropland currently so managed; in the great plains where water conservation is of utmost importance almost half of cropland is conservation tilled.

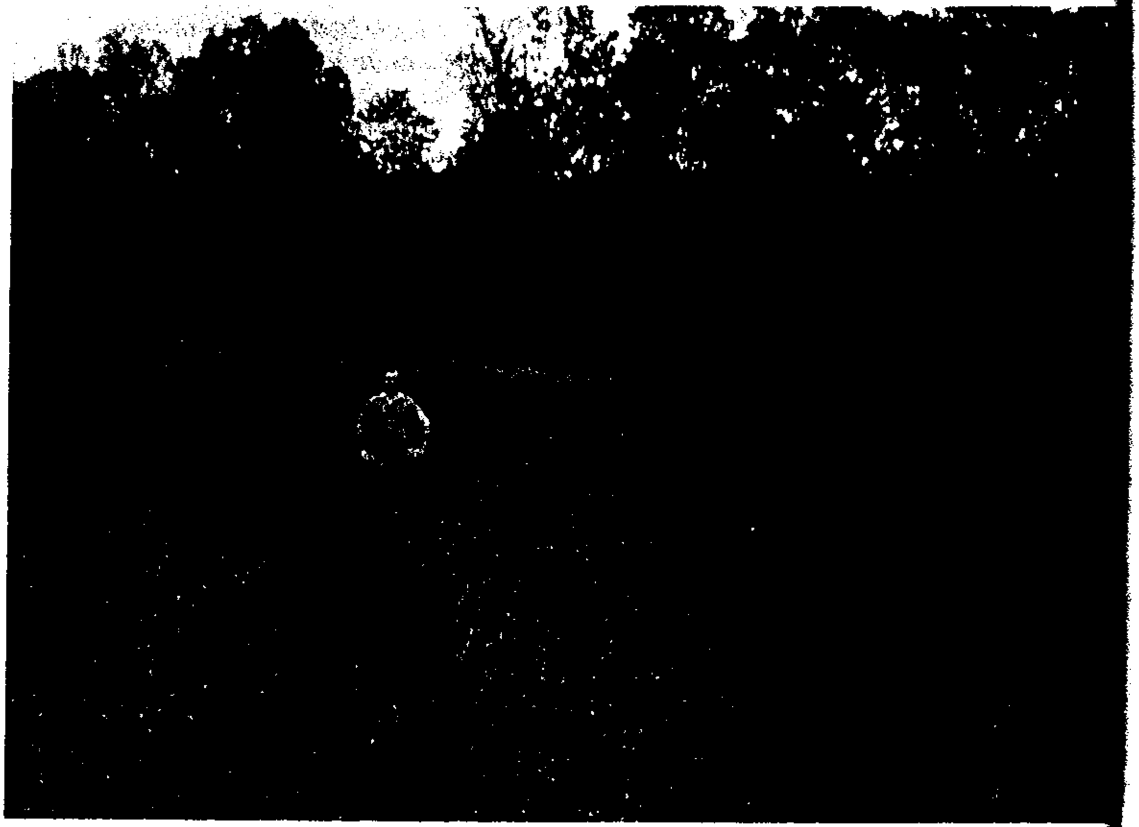
Reduced input agriculture in its various forms (conservation tillage, organic farming, alternative agriculture or regenerative agriculture, terms that are more or less synonomous) is not without its problems. Special equipment is required to plant in unplowed, heavily mulched soil and special attention has to be paid to weed control if an increase in herbicide use is to be avoided. Most of all it is important that the effect of different crop management procedures on basic ecosystem processes be understood if various aspects of cultivation (planting, insect control, harvesting and so on) are to be efficiently coordinated and integraded.

Critical organizing centers and detrital food webs in agroecosystems

For the past 10 years a team of agroecologists at the University of Georgia has been researching the effect of different planting systems on basic ecological processes such as, nutrient cycling, community metabolism, food webs and decomposition (Hendrix, et.al. 1986). In terrestrial ecosystems, both natural and domesticated, the litter-soil zone functions as a *critical organizing center* that controls the overall funtioning of the whole ecosystem. It is in the detritus food web that the rate and chemical nature of decomposition is determined which in turn specifies the quantity and quality of nutrients available for uptake by the autotrophs. Theoretically, not only the pattern of primary production but also the resistence and/or resilience of an ecosystem is determined by the responsiveness and storage capacity of detritus processing components. Contrasting conventional and no-tillage agroecosystems, one more disturbed (i.e., plowed) than the other, provide an excellent opportunity for experimental study of the litter-soil "keystone" sub-system.

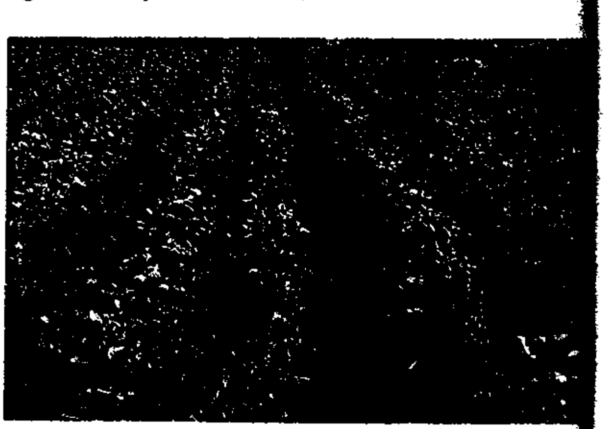
Plowing tends to break up plant residues into small pieces with release of quantities of dissolved organic matter (DOM). In contrast, residues remain in

Experiments in no-tillage agroecosystems.



Winter-spring crop of clover (to provide nitrogen) and rye (for mulch)

Preparation for planting summer grain or soybean crop. Tilled plots on right no-tilled on left



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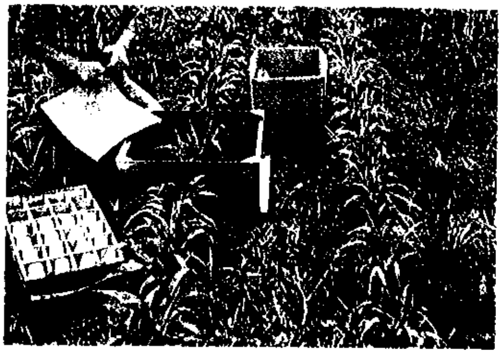
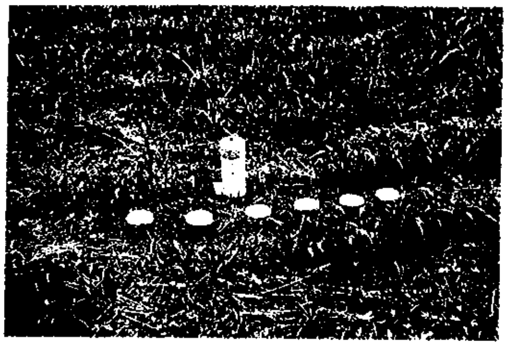
Soybeans under no-tillage

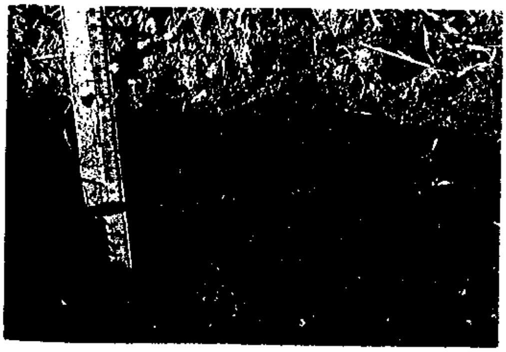


Sampling plants and soil in no-tillage plots



Soil respiration chambers

Litterbags used to measure decomposition rates and soil organism populations



Soil profile in plowed plots

Soil profile in unplowed plots (no-tillage). Note distinct organic topsoil larger pieces on the surface in the absence of plowing. We have found that no-tillage (NT) management increases the importance of fungi relative to bacteria as primary decomposers and hence as the resource base for the detrital food web. Fungi are more efficient decomposers of pieces of leaves, stems and other coarse detritus than are bacteria. Conventional tillage (CT) with frequent plowing, on the other hand, creates conditions favorable to bacteria-based food webs composed of disturbance-adapted organisms with high metabolic rates. The fungi-based and bacteria-based food chains are contrasted in Figure 5 with some of the secondary consumers associated with each food chain indicated. Thus, bacteria, protozoa, other bacterivores and small annelid worms (enchytraeids) are more abundant in CT systems while fungi, microarthropods, other fungivores and earthworms are more abundant in NT systems.

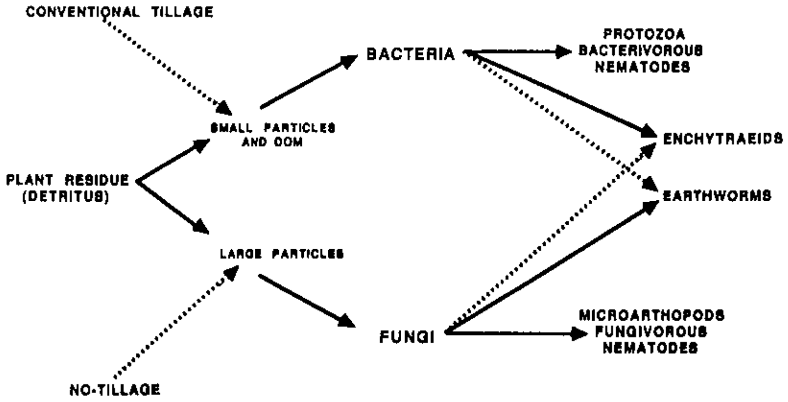


Figure 5. Effect of tillage on detrital food webs; a bacterial-based food chain predominates in conventional tillage (plowing) while a fungal-based food chain predominates in no-tillage (absence of plowing).

These detrital food web patterns are associated with faster decomposition and greater nutrient mobility in CT than in NT systems. As a result, nutrients may be more available, and crop plant growth greater, early in the season in CT. However, it has been our experience that crop plants catch up in growth later in the season as nutrients are released by the slower decomposition pattern characteristic of NT systems. Accordingly, yields at the end of the season tend to be similar in NT as in CT, other conditions being equally favorable. In general, greater immobization and slower release means that nutrients are less likely to be lost from the crop field by leaching and runoff.

Input management of fisheries and power plants

Traditionally, management of a fishery has focused on the output side of the predator-prey system, namely, control of the number harvested. However, as shown in Figure 6 there are other management options, namely, control of the number of fishermen or control of unit effort. Experience in Scandinavia and elsewhere suggests that these latter approaches that focus on the front end of

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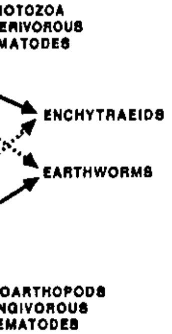

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the predator-prey chain are more effective in preventing both over fishing and under fishing than are regulations based soley on "bag limits" i.e., limiting the number of fish caught by individual fisherman. However, as far as I am aware detailed comparison of the three approaches has yet to be attempted.

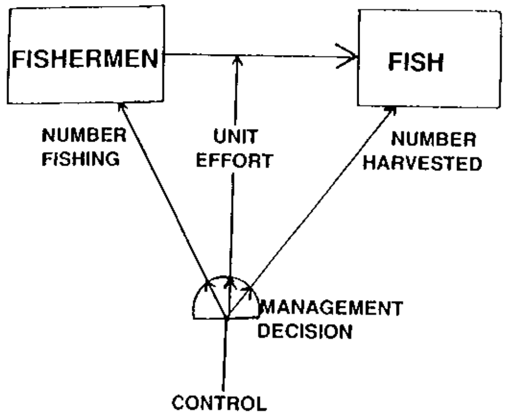

Figure 6. Management options in the control of fishery harvest "predator-prey" system.

Since power plants, especially coal-fired ones, are major contributors to acid rain and other air pollution it is vital that environmentally damaging emissions be reduced. Again attention has focused on removing pollutants by "stack scrubbers" or other technology applied to the output side even though it would seem logical that it would be ore effective to remove sulfur and other contributors to atmosphere toxification from the fuel before it is burned rather than after. Up until recently, the preceived high cost of "input management" has deterred industries and governments from taking this route. It is very encouraging that a coal gasification power plant rated the cleanest coal-fired power plant in the USA has been operating successfully and competitively with conventional power plants in California since 1984 (see Science, 232:609, 1986). At another level increasing energy efficiency of homes and buildings through insolation can greatly reduce comsumption of fuels to the great benefit of the life-support environment. In our Georgia study we estimated that if insolation of all homes and buildings were mandated, a 40% reduction in energy consumption could be achieved. Governments can do a lot to speedup coal cleanup and to promote energy efficiency in construction by providing tax relief and other incentatives.

Summary

Since non-point pollution is the major stress on earth's life-support environment, and since such pollution can not be effectively controlled from the output side of production systems, be they agricultural or industrial, then the only way to reduce the global threat of air, soil and water pollution is to reduce and manage more efficiently the inputs. Fortunately, there are increasingly strong economic and well as ecological reasons for doing just that.

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